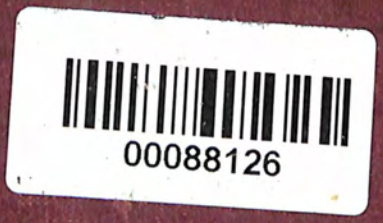
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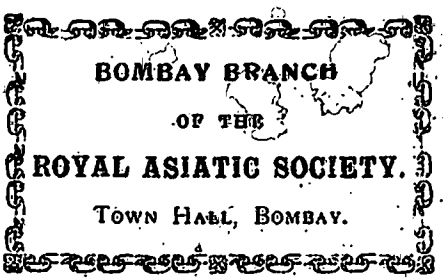

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A

TREATISE

ON

ELECTRICITY.

VOL. III.

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A

TREATISE

ON

ELECTRICITY,

IN

THEORY AND PRACTICE.

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ETC. ETC.

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TRANSLATED FOR THE AUTHOR

BY CHARLES V. WALKER, F.R.S., F.R.A.S.

SECRETARY BRIT. MET. SOC.

IN THREE VOLUMES.

VOL. III.

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LONDON:

LONGMAN, BROWN, GREEN, LONGMANS, & ROBERTS.

1858.

[*The Author reserves to himself the right of translating this Work.*]

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ADVERTISEMENT

TO

THE THIRD VOLUME.

I HAVE need to justify the delay, which has occurred in the publication of this Third and Last Volume of the *Treatise of Electricity in Theory and Practice*, which I shall do in a few words.

However vast the domain of Electricity may have become, so long as the theory alone is in question, it is easy to him who has devoted himself to the study of this branch of science to keep pace with all that relates to it. But, if from the theory we pass on to the application, other kinds of knowledge in very great abundance become necessary; the portions which are discussed in this Third Volume are the proof of this. Thus the physical applications depend, in respect to the majority of them, upon delicate notions of practical mechanics; the chemical applications require very special metallurgical knowledge; finally, the therapeutical applications demand an accurate appreciation of physiological and medical questions. This simple enumeration suffices to make our readers comprehend the difficulties that I have encountered in the composition of this Third Volume; and it may be conceived without difficulty that its publication has been delayed by the desire, that I entertained, of informing myself from the persons who are occupied in the subjects that I have been called upon to discuss, both by consulting their works, as well as by conversing with them. It is

especially in that which concerns therapeutic applications that this double resource has been valuable to me; and, in this respect, I am enabled to mention, as having been especially useful, the work of M. Duchenne of Boulogne, *On Localized Electrization;* and the *Treatise on the applications of Electricity to Therapeutics*, by Dr. A. Becquerel. I am also happy to have the advantage of this opportunity of addressing my best thanks to the Directors of the various Observatories for the kindness with which they have so willingly communicated to me the magnetic elements of the various stations in which their observations are made. The results, which they have communicated to me, are contained in the final Note C.

I must add that my task, as far as concerns this Third Volume, has been singularly facilitated for me by the co-operation that has been afforded me by my son, M. Lucien de la Rive, former pupil of the Polytechnic School of Paris, by his undertaking the reduction of the mathematical notes with which the Volume is terminated, and of the Second and Fourth Sections of the Chapter on Physical Applications, relative to the application of the magnetic properties of the current, both to the production of a mechanical motor, as well as to the various apparatus, other than electric telegraphs.

Within the interval of the five years that have elapsed since the publication of the First and that of this Third Volume of the Treatise, many labours, having relation to the matters which form the subject of the first Two Volumes, have originated in the scientific world. In order that my work may be as much as possible parallel with the state of science at the end of 1857, I have endeavoured to present in an Appendix a summary of the new researches, to which I have just made allusion. Happily for my labours, no discovery of a very great importance has signalized the study of electricity during these last years; so that we may consider the present period as a momentary resting time in the march of the science; a circumstance eminently

favourable to a publication of the kind that I have undertaken.

Besides, the works that have appeared, far from contradicting the theories that I have put forth, have rather come to confirm them; and in particular, to give a new support to the observations that I had presented in the preface of my First Volume, on the part played by Electricity in the Physical Sciences. Thus the remarkable phase into which the experimental sciences seem to enter, as the result of the facts that tend to establish upon bases, more and more solid, the principle of the correlation of the physical forces, is of a nature to enlarge further the domain of Electricity. We here, in fact, find one proof to add to so many others, that Electricity is one of the most frequent forms which the different forces of nature assume in their transformations; and that it thus constitutes the link by which they are united to each other, while still leaving them subordinate at the same time to the action of that providential Power, which maintains all the parts of the universe in equilibrio.

Geneva: January, 1858.

CONTENTS

OF

THE THIRD VOLUME.

PART VI.

RELATIONS OF ELECTRICITY WITH NATURAL PHENOMENA.

CHAPTER I.

PRODUCTION OF ELECTRICITY IN PHYSIOLOGICAL ACTIONS.

	Page
General Notions upon Physiological Electricity, and particularly upon Animal Electricity - - - -	1
Of the Current Proper of the Frog, and of the Muscular Current in general - - - - - -	8
Theory of the Muscular Current. — Influence of various Causes, and in particular of Contraction, over the Intensity of this Current. — Induced or Secondary Contraction	23
Of the Nervous Current - - - - - -	41
Relation between the Muscular Current and the Nervous Current, and Physiological Consequences - -	50
Electric Fishes - - - - - - -	62
Production of Electricity in Vegetables - - -	83

CHAPTER II.

ATMOSPHERIC ELECTRICITY.

The existence of Atmospheric Electricity, and the means of proving it - - - - - - -	90
Study of the Electricity of the Atmosphere in the Normal State - - - - - - - -	99

Page

Of Storms and of the Electric Phenomena that accompany them - - - - - - - - 114
Of the fall of Lightning; of the Phenomena that accompany it; of the means of Protection from it; Lightning Conductors - - - - - - - - 138
Of the Part played by Atmospheric Electricity in Meteorological Phenomena - - - - - 167
Origin of Atmospheric Electricity - - - - 190

CHAPTER III.

TERRESTRIAL MAGNETISM.

Description and Theory of the Instruments - - 202
Results of Observations relative to the Determination of the Elements of Terrestrial Magnetism and of their Variations 222
Hypotheses on the Causes of the Phenomena of Terrestrial Magnetism - - - - - - - 266
Natural Phenomena connected with Terrestrial Magnetism; Auroræ Boreales - - - - - - 283

PART VII.

APPLICATIONS OF ELECTRICITY.

CHAPTER I.

PHYSICAL APPLICATIONS.

Application of Electricity to the Production of Light and Heat - - - - - - - - 310
Application of the Magnetic Properties of the Current to the Production of a Mechanical Motor - - - - 324
Application to Telegraphy - - - - - - 347
Needle Telegraphs - - - - - - - 355
Dial Telegraphs - - - - - - - 375
Registering Telegraphs - - - - - - 396

Page
Magneto-Electric Telegraphs - - - - 424
Conductors employed in Telegraphic Lines. — Simultaneous Transmission of two Despatches by a single Conductor in contrary Directions - - - - - 428
Employment of the Electric Telegraph in Scientific, and more particularly in Astronomical Observations - - 463
Electric Clocks - - - - - - 471
Chronoscopes - - - - - - 484
Electric Bells - - - - - - 486
Electric Weaving - - - - - - 487
Apparatus for maintaining the Motion of the Foucault Pendulum - - - - - - - 496
Electro-Sorting Apparatus - - - - - 499
Application of Electro-Magnetism to the Adhesion of Locomotives upon the Rails, to the Transmission of Motion, and to applying the Breaks of Trains - - - 502
Electric Registers - - - - - - - 505

CHAPTER II.

CHEMICAL APPLICATIONS.

General Considerations upon Electro-Chemical Forces and their Applications - - - - - 512
Application to the Preparation of Simple Bodies - - 530
Applications to the Formation of Metallic Deposits in thin Films; Gilding, Silvering, &c. - - - - 545
Application to Galvano-Plastics - - - - 566

CHAPTER III.

PHYSIOLOGICAL OR THERAPEUTIC APPLICATIONS.

General View on the Application of Electricity to the Art of Healing, and Description of the Apparatus employed - 586
Analysis of the Direct Therapeutic Effects of Electricity - 609
Examination of Particular Cases to which Electric Therapeutics is applicable - - - - - 633
Indirect Therapeutic Effects of Electricity - - - 678
Physiological Effects of Atmospheric Electricity - - 693

APPENDIX.

Page

1. Recent Researches upon Electro-Static Induction - 705
2. Influence of Mechanical Actions upon Magnetization - 711
3. Influence of Temperature upon Magnetism - - 716
4. M. Felici's Theory of Electro-dynamic Induction - 719
5. Improvements introduced into Induction Apparatus - 722
6. New Researches on Diamagnetic Polarity, and on Diamagnetism in general - - - - 729
7. Optical Properties of transparent Bodies, subjected to the Action of Magnetism - - - - 740
8. Reduction of the Measures of Intensity of Currents to Mechanical Units by MM. Weber and Kohlrausch - 744
9. Researches relative to Conductibility - - - 747
10. New Experiments for proving that the Transmission of Electricity through Liquids is always accompanied by their Electrolytic Decomposition - - - 753
11. Phenomena of Transport in Electrolysis - - - 758
12. Researches on the Electro-motive Force - - 765
13. Transformation of Electric Heat into Mechanical Work 771
14. Researches Relative to Electric Fishes - - - 777
15. New Researches upon the Variations of the Magnetic Elements of the Terrestrial Globe - - - 779
16. M. Wartmann's Process for establishing an immediate Correspondence between any two of the Stations situated upon a same Telegraphic Line - - - 783

NOTES

RELATIVE TO MATHEMATICAL DEVELOPMENTS OF CERTAIN PARTICULAR POINTS.

Page

NOTE A. (p. 209.)

Note relative to the Absolute Measure of the Intensity of Terrestrial Magnetism - - - - - - 787

NOTE B. (p. 215.)

Note on the Bi-filar Magnetometer - - - - 802

NOTE C. (p. 259.)

Relative to the Determinations of the Magnetic Elements of the Principal Stations of the Terrestrial Globe - - 807

NOTE D. (p. 342.)

Note upon Electro-Motors - - - - - 812

TREATISE ON ELECTRICITY

IN

THEORY AND PRACTICE.

PART VI.

RELATIONS OF ELECTRICITY WITH NATURAL PHENOMENA.

CHAPTER I.

PRODUCTION OF ELECTRICITY IN PHYSIOLOGICAL ACTIONS.

General Notions upon Physiological Electricity, and particularly upon Animal Electricity.

We saw, when we were occupied with the sources of electricity, that every action, or rather every change, in the molecular state of a body, is accompanied with a liberation of electricity, whether this change takes place through the effect of a physical action, such as heat, or of a mechanical or a chemical action. But independently of these simple actions, brought about by the hand of man, there exist in Nature a multitude of spontaneous actions, more or less complex, that give rise to divers phenomena, which are presented to us either by organised or by inorganic bodies; these actions are in like manner accompanied by electric manifestations. When the bodies, which are the subjects of them, are inorganic, they must of necessity be like unto those whose effect we

have studied in the Fifth Part, either physical, mechanical, or chemical; only, as they are not presented under such simple circumstances, we must endeavour to sift them out, in order to explain the origin of the electricity, that results from them. But when the bodies are organic, the difficulty still increases, at least when a living organism is the subject of inquiry; we must then take account of a new and important force, namely, vital force. Indeed, we shall see that the action of this force is attended, in all bodies wherein it exists, by a production of electricity, which is constantly manifested, although under very varied forms, and in very different degrees of intensity, and which ceases with the phenomena themselves. The problem is then complicated with the question, to know whether the electric manifestations are a direct and immediate consequence of vital force, or whether they arise from the physico- or chemico-physiological actions, that are brought about by this force, and of which they would then be but an indirect effect. It follows, indeed, as a matter of course, that, as far as we are concerned, vital force itself is not a resultant of the physical or chemical forces that accompany the presence of life, but that, on the contrary, it rules over them, and sets them into activity, so as to cause them to be subservient to the accomplishment of the functions which constitute the living organism.

Besides, whatever may be the cause of the electricity that is manifested, under one form or another, by every body endowed with life, we name this cause *physiological action;* and it is by the study of the electric phenomena which accompany physiological actions, that we commence this Sixth Part, by devoting this first paragraph to a general glance over this subject, into the details of which we shall enter in a more particular manner in the following paragraphs.

It is for the most part in animals that the electric phenomena, which accompany the presence of life, have been recognised and studied *; and among animals, it is first in certain fishes that the most decided signs of it have been observed.

* We shall see further on the attempts that have been made to detect the presence of electricity in living vegetables.

There exist certain species of fish—among others, the *torpedo*, the *gymnotus*, and the *silurus*,—which give a violent shock when they are irritated in certain parts of the body; and it was very quickly proved that this effect was due to an electric discharge, by remarking that, in order to experience it, it was necessary to touch the fish with a rod a conductor of electricity. Subsequently this electricity was itself collected; and it was proved that it possessed all the properties of electricity developed by artificial means. We shall study in a following paragraph this remarkable source of electricity, by examining closely the structure and the properties of the particular organ that seems to produce it, and with which the electrical fishes alone are endowed. First of all we must occupy ourselves with the electric manifestations, that we have succeeded in observing, but in a much less degree, in other animals.

Galvani was the first who demonstrated the existence of animal electricity in the frog. We have quoted the fundamental experiment upon which he had thought he was able at first to rest his demonstration *, and which consisted in placing in communication the nerves and muscles of a frog, by means of an arc composed of two metals. But the interpretation that Volta gave of it, by proving directly that the employment of an heterogeneous metallic arc was the origin of the electricity, compelled Galvani to employ an homogeneous arc in order to unite the muscles and nerves of the frog. A very long discussion then arose between Volta and Galvani, and their respective partisans, relative to the cause of the contractions experienced by the frog in the fundamental experiment, Volta attributing them to the electricity developed by the contact of heterogeneous substances, and Galvani persisting in assuming the existence of an animal electricity, of which he supposed the negative as being condensed in the interior parts of the muscle, whilst the positive was at its surface, the nerve serving as conductor between the two coatings of this species of Leyden jar,—an idea that we shall see to be very near to the truth. Nothing is more ingenious

* Vol. I. p. 29.

than the experiments by which Volta endeavoured to demonstrate that the slightest difference in the homogeneity of conducting bodies in contact was sufficient to give rise to an electricity rendered sensible by the contractions of the frog, this electricity being in all cases, according to him, due to an heterogeneity in the metallic arc. Galvani, on his side, and his nephew Aldini, showed that contractions might be produced with perfectly homogeneous metallic arcs, or without employing metals; and they attributed the incontestible influence of heterogeneity only to an increase of resistance, which rendered the discharge of the animal electricity more powerful. The fundamental experiment on which Galvani based the existence of an animal electricity, consisted in cutting the nerves at their exit from the vertebral canal; then, in raising them delicately with an insulating rod, so as to bring them into contact with the exterior surface of one of the thighs of the frog in a single point of the muscle, if it is possible: and the thigh immediately contracted. Galvani had even succeeded in obtaining the contraction of the thigh of a frog, by placing its nerve in contact with a foreign muscle, such as a muscular fragment of the belly, placed on a plate of glass, and which had no conducting connection with the frog. This remarkable form, given by Galvani to his fundamental experiment, constitutes, as we shall see, one of the most curious phenomena of animal electricity. However, Volta having further objected that the electricity developed in this latter experiment was due to the contact of the muscle and the nerve, and entered consequently into the general principle that he had established on the electricity of contact, Galvani placed on an insulating plane a thigh of a frog, furnished with its nerve bent into a semi-circle; in the neighbourhood, and without communication with the former, he placed a second thigh, and allowed the nerve of this latter prepared thigh to fall upon the bent nerve of the former. In this manner, at the two points of contact there was nothing but the nervous substance: all was therefore homogeneous; and yet, at the moment when the two circuits were thus closed, the two thighs contracted energetically.

Galvani did not confine himself to experiments upon frogs; he also made some upon warm-blooded animals, and succeeded in showing that the current of animal electricity directed from the inferior extremity of the limbs toward the nerves, was not peculiar to the frog merely, but was found in other animals. These results, doubted for a long time, have been subsequently confirmed and extended by the beautiful researches of Matteucci and of Dubois-Reymond. Nevertheless, at the period of which we are speaking, the ideas of Volta finally predominated over those of his adversary, the learned world being unable to refuse to give credit to the philosopher who, travelling from fact to fact with an admirable logic, and an equally large power of observation, had been led from the scarcely sensible discharge of electricity, that is detected by the contraction of the frog, to the voltaic pile, the most energetic source of electricity that man has hitherto produced.

However, like as Galvani and his partisans had gone too far in seeing in the contractions of the frog only an effect of animal electricity, whatever might have been the conditions of the experiment, Volta and his partisans were wrong to deny absolutely the existence of this electricity. This had been greatly felt by the illustrious philosopher who has been one of the greatest glories of modern Europe, without allowing himself to be swayed by the then all-powerful authority of Volta. In a work published in 1797, and of which we have already made known some of the results*, Humboldt described a series of experiments, by which he had succeeded in producing contraction in the thighs of the frog by merely placing in contact the nerve and the muscle, and taking care to avoid all mechanical irritation. He obtained contractions either by bending back the lumbar region of the animal toward the ischial nerve, with which it was still organically connected, or by touching at the same time, by means of a fragment cut from the crural nerve, the crural nerve and a muscle of the thigh, or by touching the nerve of

* Vol II. p. 490.

the prepared frog on two different points, with a piece of the muscular substance taken from the living frog. Humboldt had likewise demonstrated the possibility of contractions produced by arcs really homogeneous; and he had established the following distinction, by means of which he had succeeded in reconciling, in a very correct manner, Galvani's results and those of Volta; namely, that if it is true that there are animals with which an homogeneous arc does not excite any contraction, whilst these same animals give manifestations of it as soon as the arc is the least in the world heterogeneous, on the other hand, we are unable to admit that muscular contraction cannot take place, except so long as there is heterogeneity.

Animal electricity, amidst the discoveries so numerous and so brilliant to which Volta's pile had given rise, had been completely lost sight of, when, thirty years after the publication of Humboldt's work, namely in 1827, Nobili, taking advantage of the means of investigation which the science of electricity had acquired during this interval of time, succeeded in proving, in a manner irrefragable and free from every objection, the existence of an electric current in the frog, which he named the current proper of the frog. It was by using a very sensible multiplier galvanometer, which he had just invented, and which we have described, that he was able to collect this current. The frog being prepared after Galvani's method, he caused it to plunge, on the one part by its lumbar nerves, on the other part by its legs, into two capsules filled with pure water, or, which is better, with salt water.* He first satisfied himself, by connecting the two capsules by a hank of moistened cotton, that the frog contracted, as Galvani, Humboldt, and others had already observed; then, removing the hank of cotton, he closed the circuit by plunging respectively into the two capsules each of the extremities of his galvanometer, terminated by plates of platinum. He thus obtained a current of 10°, 20°, and even 30°; this current was of a few degrees only when the

* *Vide* Vol. II. p. 498. *fig.* 258.

liquid contained in the capsules was pure water, in place of the more conducteous salt water. It was, moreover, invariably directed in the animal from the feet to the head, or from the muscles to the nerves.

Nobili observed many important facts on the current of the frog. Although the frogs did not contract under the action of their current proper, except for a short time, at most for a quarter of an hour, after they had been prepared, yet the action of this same current upon the galvanometer is of a much greater duration, of several hours in many cases. Having obtained a deviation of 5° with a frog, he arranged a second one in the circuit, after the first one and in the same direction; and the deviation was then 8°; with a third the deviation was 11°. Upon opposing the current of one frog to the current of another, there is no longer any effect; thus there is not even any contraction either in one or in the other of the two frogs on touching the nerve and the muscle of one respectively with the nerve and muscle of the other, whilst they both contract powerfully when the nerve of the one is placed in reciprocal contact with the muscle of the other.

The existence of a current proper in the frog, and independent of every exterior cause, although well established by Nobili, had not attracted all the attention that it merited. It is to the efforts and labours of M. Matteucci that we are indebted for having placed in relief the importance of this fact, and, in general, for having restored to animal electricity the place which it ought to occupy in electrical and physiological phenomena. Another philosopher, M. Dubois-Reymond, has likewise made electro-physiological phenomena, as we have already said*, the subject of labours that are as numerous as they are conscientious. It is essentially from the researches of these two philosophers that we shall extract the details, into which we are about to enter upon this delicate subject,—details indispensable to know for our understanding the Part of Applications, the object of which will be therapeutics.

* Vol. II. p. 511.

Of the Current Proper of the Frog, and of the Muscular Current in general.

Matteucci and Dubois-Reymond have each of them equally employed the galvanometer and the galvanoscopic frog for observing electro-physiological phenomena. We have pointed out the manner of preparing this galvanoscopic frog and using it*; we shall continue to call by this name the physiological galvanometer, even when, instead of being formed with an entire frog, it is composed of only a thigh of a frog furnished with its nerve, as represented in *fig.* 262. We shall therefore confine ourselves here to enumerating the precautions to be taken in the employment of these two processes, especially of the former. Indeed, when the galvanoscopic frog is in question, we must simply take care well to expose the nerve, and to close the circuit with the nerve alone, without including in it any portion of the muscle of the leg. The nervous filament must be touched with the two points that are suspected to be the poles of the electro-motor element that we desire to study; and if the portion of the nervous filament comprised between these two points of contact is effectively traversed by an electric current, the leg is in an instant seen to contract. We may even with a very great degree of probability determine the direction of this current. For this purpose, we have merely to employ a frog's leg that is a little enfeebled; and then, if the current is directed in the nerve from the side next the leg, we see this latter contract when the circuit is closed, and, on the contrary, remain motionless at the moment when the circuit is opened. The reverse takes place if the current has a contrary direction. We may, without inconvenience, if we desire to avoid direct contact with the points of the electro-motor element, interpose between the nerve and these points two small bands of paper moistened with water.

The employment of the galvanometer requires more precaution. It is necessary first to avoid the chemical action of the animal liquids upon the plates of metal which serve

* Vol. II. pp. 513. and following pages; *fig.* 262.

to place in the circuit the various organs whose electric state we are desirous of studying. With this view we make use of plates of a very pure platinum, of the same surface, which have been cleaned with much care; we must even allow them to plunge into water for a very long time, in order that this simple immersion may not give rise to a current; then, when we are satisfied that there is no action, we touch at the same time with the two plates the animal parts in which we are seeking for the electric current, taking care to hold these plates by varnished handles, to which they are fixed. But the mere fact of the circulation of a current by polarising the plates renders them capable of producing, without any other cause, a current which we have called secondary. We are unable, therefore, to operate twice consecutively, without having taken care well to depolarise the plates after the first experiment, which is done by leaving them plunged in a same liquid for a certain time, still preserving between them a metallic communication. It is even advantageous, in order to avoid the weakening that results to the current from this polarisation in a same experiment, to observe the deviation that is obtained at the first instant, instead of waiting to note it until it has become constant, namely, until the needle is at rest.

To the precautions that we have just indicated, according to Matteucci, Dubois-Reymond added several others besides; which are all the more indispensable as, proceeding with his very sensitive galvanometer multipliers, it was necessary to avoid every chance of error, which the excessive delicacy of his instrument rendered greater. The following is his mode of proceeding. He makes the extremities of his galvanometer communicate with two plates of platinum, each fixed in metal pincers at the extremity of a horizontal brass rod, which is itself adapted to a similar but vertical rod, along which it is able to slide, and which is insulated, by means of a small glass column. The platinum plates plunge into a vessel, and can thus have at pleasure a motion in a horizontal or a vertical direction. One of the extremities of the wire of the multiplier is adapted to the other end of the horizontal rod. The

figure (326.) represents this arrangement, of which there are two similar ones, one for each of the extremities of the galvanometer. Each platinum plate is 2½ inches high, and 1 inch wide. The vessels into which they plunge are filled with a concentrated solution of kitchen salt; and care is taken, so long as operations are not in progress, to retain the circuit constantly closed, by means of a siphon filled with the same solution, which unites the liquids of the two vessels.

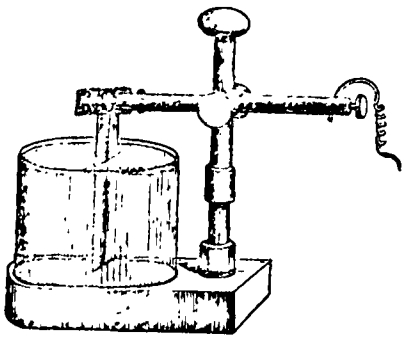

Fig. 326.

Now, when we wish to operate, it is preferable, instead of removing the platinum plates in order to apply them to the animal parts that are about to be tested, to unite the two vessels by means of these parts after having removed the siphon, thus leaving the plates at rest in the liquid wherein they are immersed. But the immediate immersion of the animal parts in the saline solution is not convenient when delicate experiments are in question, on account of the disturbances that may arise from the corrosive action that is exercised upon these parts by the concentrated solution. In order to avoid it, M. Dubois-Reymond employed cushions or bundles formed of a very great number of layers of a very thin paper, which, moistened with the saline solution, are applied on the edge of the vessels of communication (*fig.* 327.). A third pad serves to close the circuit, by uniting the two former when operations are not going on, and in order to depolarise the plates after we have operated. We have thus a secondary current, the reverse of the primary current, and the intensity of which is proportional to that of

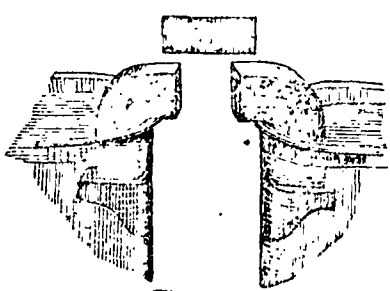

Fig. 327.

this latter. This current afterwards ceases when the plates are depolarised; and the experiment may be again commenced. In order to introduce into the circuit the animal part whose electric state we are desirous of testing, we begin by removing the additional pad; then, instead of placing the animal part immediately in contact with the conducting cushions moistened with the saline solution, which might bring about the corrosion of which we have spoken, the surface of these pads is covered with a skin of pig's bladder, upon which has been spread some white of egg: the electric communication is not arrested; and we nevertheless avoid thus all immediate contact between the animal parts and the saline solution.

M. Matteucci, after many researches upon the current proper of the frog, to which we shall return presently, succeeded in proving the existence of a muscular electric current. It was by cutting the muscle of a living animal, and introducing into the wound the nerve of the galvanoscopic frog, so that the end of the nerve touched the bottom of the wound, whilst another point of the same nerve touched the edges, that he obtained a decided contraction of the frog, which proves the existence of an electric current, directed, in the muscle, from the interior to the surface. The experiment succeeds whatever be the muscle, and whatever be the animal whose muscle is touched, and even when the muscles have been separated from the animal for some time. With a rabbit M. Matteucci obtained a powerful contraction of the muscle of the leg, by placing in contact with the surface of this muscle the crural nerve, of which a portion of sufficient length had been laid bare.

In order to render the effect of the muscular current more sensible, and to obtain decided signs of it upon the galvanometer, M. Matteucci has succeeded in increasing its intensity, by uniting several separated muscles, as if to form with them a species of pile. Thus having prepared a certain number of half-thighs of frogs, he arranged them one after the other so that, while being in contact, the internal face of each of them was turned on the same side (*fig.* 328.). Thus in each point of contact of two neighbouring half-thighs, it is on the one

hand the interior of the muscle, on the other the surface that touch each other; so that, in consequence of this arrange-

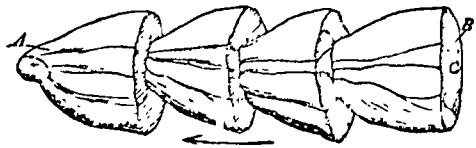

Fig. 328.

ment, one of the extremities of the pile is terminated by the interior of the muscle, whilst the other is formed by the surface. The two extremities are in communication with distilled water, in which are plunged the platinum plates of the galvanometer, after being assured that, when immersed in the same liquid, they do not transmit any current. Immediately, a current is obtained which varies in intensity with the number of half-thighs of frog of which the pile is composed; it is about 3° or 4° with two, from 6° to 8° with four, from 10° to 12° with six. If, for establishing communication with the plates of the galvanometer, we employ water slightly acid, saline, or alkaline, we obtain a considerable increase in the intensity of the current, without its direction being modified. This direction is such that the current is always directed, in the pile, from the internal part of the muscle to its surface. We can in the same manner prove the existence of this current in all the muscular masses taken from different hot- and cold-blooded animals recently killed. Thus, a pile of eight pairs, formed with slices of the pectoral muscles of the pigeon, recently killed, gave a current of 14°, always directed, in the pile, from the interior of the muscle to the surface. M. Matteucci has greatly varied his experiments; and they have all led him to the same conclusion. He has even succeeded in proving the existence of this current upon a living animal, such as a rabbit, a sheep, a pigeon, by wounding a muscle of its breast or its thigh, after having exposed its surface, and touching at the same time, with the two plates of the galvanometer, the interior of the wound and the surface of the muscle, which gave rise to a current of

20° or 30°, and even 40°, moving always, in the muscle, from the interior to the surface.

Upon opposing to each other, by means of a differential galvanometer, the currents of two piles composed of the same number of muscular elements, M. Matteucci found that the least powerful current is that which is produced by the muscles of the animal the highest in the scale of beings; but this difference may be less due to an original feebler intensity, than to the more rapid weakening of the current in animals higher in the scale.

The existence of a muscular current being well proved, M. Matteucci made the current proper of the frog the object of a detailed examination. We have already stated further back how Nobili had succeeded in proving, by means of the galvanometer, the existence of this current, which is always directed from the feet to the head in the body of the animal, and consequently from the nerve to the leg in the galvanometer. The intensity of this current varies, all other circumstances remaining the same, with the vitality proper of the animal. If the frog is robust, and has been promptly prepared, its muscles are seen to contract at the very moment when the circuit is closed with the galvanometer. M. Matteucci succeeded in increasing the signs of this current by arranging several frogs, prepared according to Galvani's method, one after the other upon an insulating plane, so that the nerves of each frog are in contact with the legs of the following. The two extremities of this pile plunge into two capsules filled with water either distilled or slightly salt. The current is always directed from the feet to the head in each of the frogs. All the frogs are frequently seen to contract at the moment when the circuit is closed with the wire of the galvanometer. Besides, this contraction, which is due to the current proper of the frog, is brought about whatever be the conductor that is employed for uniting the muscles of the leg with the lumbar nerves laid bare.

The signs of the current proper of the frog are more or less prolonged, according to the degree of vitality of the animal. The contraction proper generally ceases after ten or

fifteen minutes; it is very rare that it is prolonged to thirty; but on the galvanometer the signs of the current endure for a longer time. Thus three piles of eight or ten frogs, which gave at the commencement a deviation of 30° or 40° on the galvanometer, produced it still at the end of a quarter of an hour. They still gave a sensible deviation after several hours; and it was frequently necessary that more than a day should elapse in order to their no longer giving it.

Upon arranging the frogs so as to oppose their currents, and on studying the effect of the different parts of the body of the animal, M. Matteucci succeeded in recognising that the complete electro-motor element of the frog is formed by one of its limbs, itself composed of a leg, a thigh, its spinal nerve, and a piece of the spine. He has moreover concluded from various experiments: — 1st, that the current proper of the frog persists, in its direction and its intensity, without the spinal marrow, without the spinal and crural nerves, and although the animal is deprived of all the nervous filaments of the muscular mass of the thigh; 2nd, that consequently the electro-motor element is reduced to the muscles of the leg and of the thigh united organically; 3rd, that when there remain to the frog prepared in the ordinary manner, its spinal marrow, its nerves, and its ramifications in the muscle, these nervous parts act in the production of the current, as does the muscular substance of the thigh.

It follows from this that the function of the nervous system in the production of the muscular current, as in that of the current proper of the frog, seems to be reduced to that of a body simply a conductor of the current developed in the part of the muscle to which it is nearest. M. Matteucci has confirmed this conclusion by direct experiments made upon the thighs of the frog, to which he had left the lumbar nerve, placing each nervous filament upon the muscular surface of each thigh; he thus obtained, with a pile of eight elements, a muscular current directed from the muscle to the nerve, or rather from the interior of the muscle to its surface through the nerve, which acts as the interior of the muscle in which it is ramified. We succeed equally well with the

legs of the rabbit or of the pigeon, by exposing in these legs the nervous filament, or the crural nerve, that is concealed in the muscle; and the pile is formed by causing the nerve in each element to touch, instead of the interior of the muscle, its surface. These piles give the same muscular current; only this current is in all cases more feeble when the nervous filament forms part of the circuit. Thus, whether in the current proper of the frog or in the muscular current, the direction of the current is altogether independent of the presence of the nerve, which acts merely as a bad conductor, representing the electric state of the part of the muscle which is nearest to it. A very evident manner of confirming this conclusion consists in cutting through the middle (removing from them the lower part) the thighs of frogs separated from their legs, but having preserved their lumbar nerves; then the pile is formed with these elements by making the nerve touch the interior of the muscle (*fig.* 329.). This pile gives

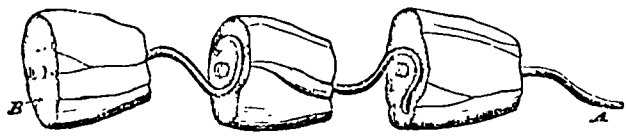

Fig. 329.

the muscular current always directed from the interior of the muscle to the surface; that is to say, in this case, from the interior of the muscle to the nerve, which communicates with the surface of the muscle. Thus, although relatively to the nerve the direction of the current ought to be reversed, it remains the same, because the parts of the muscle are arranged in the same manner with respect to each other. On arranging

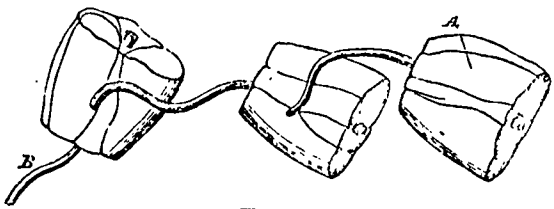

Fig. 330.

the pile differently, so that the nervous filament of each frog rests no longer on the interior part, but on the surface itself

of the muscle of each thigh (*fig.* 330.), we then have nothing more than a very feeble current, which is directed as if the entire thigh was in the circuit, namely, from the upper part of the semi-thigh, or from the lumbar nerve, to the surface of the muscle in the animal. This slight current is due to the small portion of the muscle that we were obliged to lay bare on cutting the pelvis.

With regard to the analogy that seems to exist between the muscular current and the current proper of the frog, M. Matteucci, while still putting it forward, had not demonstrated it. He had, in fact, endeavoured in vain to find in other animals the existence of a current analogous to that of the current proper of the frog; and he had only found the muscular current, which the frog likewise gives at the same time that it presents its current proper, which is obtained without altering the muscle, without laying bare its internal part, and which is directed from the surface of the muscle to its nerve in the animal. He seemed, then, disposed, consulting only the experimental mode, to recognise no identity between the two species of current. It is true that more recently he had been led to a contrary opinion, in studying the part played by the tendinous fibre, which composes the greater part of the leg of the frog, in the production of the current proper of this animal, at the same time that M. Cima also succeeded, on his part, by the same kind of considerations, in reducing the current proper of the frog to a particular case of the muscular current. But at this epoch, as M. Matteucci has himself acknowledged, M. Dubois-Reymond had already proved this identity by the knowledge of the elementary laws of the muscular current, that he had discovered (and which we are about to state) in the outset by the researches that he made on this same current proper of the frog: a point of departure, since Galvani's time, of all the important labours on electro-physiology.

After having proved, by means of his apparatus furnished with all its pieces, and according to the method already described, the existence of this current in the ordinary frog (*Rana esculenta*), M. Dubois-Reymond succeeded in demon-

strating its existence, although in a more feeble degree, in other species of frogs as well as in tortoises, as Humboldt had already observed in the *Salamandra maculata*, in the *Lacerta agilis*, and even in a leg of a pigeon and in that of a rabbit. Afterwards, on studying the different manners of producing the contractions of the frog by its current proper, without the intervention of any metal, he found that one of the best is that employed by Nobili, and which consists in placing upon an insulating plane two frogs, prepared by Galvani's method, so that they form a circuit in which the nerves of each are in contact with the muscles of the other.

M. Dubois-Reymond soon recognised, in the production of this current, the part played by the gastrocnemian muscle of the frog, by means of which he succeeded in determining either a contraction in a prepared frog, or a deviation of the galvanometer. In order to obtain this deviation, he detached by its tendinous extremities the gastrocnemian muscle of the frog, without wounding the flesh; then he placed it across the two pads, so that the extremity on the side of the tendon Achilles extended more over the cushion than the other; and he obtained a current directed in the muscle from the former extremity to the latter, and consequently having the same direction as in the frog. Other muscles, both of the frog and of other hot-blooded and cold-blooded animals, placed in the same manner, give rise to currents directed sometimes in one direction, sometimes in another. However, these differences of direction appeared to M. Dubois-Reymond to arise from differences of conditions under which they were obtained, rather than from difference in the electro-motive power of the muscles. He strove greatly therefore, after having well established that the current proper of the frog was due to muscular currents, to make these currents manifest under their most simple form, and to determine their laws.

In order to find the law of the muscular current, it is necessary first to study the manner in which one and the same muscle behaves, according to the mode in which it is placed upon the cushions that are employed to place it in the circuit of the galvanometer. For this purpose a muscle is

taken which, being placed between the two cushions so as to be in contact with them by its tendinous extremities, being at the same time supported by a small plate of glass (*fig.* 331.),

Fig. 331.

Fig. 332.

does not give rise to any current; the great adductor muscle is one of the most convenient for this kind of experiment, because it is the one whose form is most symmetrical. If now the muscle is so arranged (*fig.* 332.) that one of its extremities, *a*, is in contact with one of the cushions, whilst, by raising the other extremity, *b*, it is the red flesh of the muscle that is in contact with the other cushion, a very powerful current is obtained, which goes in the muscle from the tendinous extremity towards the touched point of the muscular flesh. If, after having destroyed the secondary polarities by making the cushions communicate with each other by means of the auxiliary cushion (*fig.* 327.), the muscle is arranged in a similar manner, but in such a way that it is its extremity *b* that is in contact with the cushion (*fig.* 333.), a very powerful current is then obtained, always directed from the tendinous extremity toward the muscular flesh. It follows from this double experiment, that if *a* is found to be the upper extremity of the muscle in the animal, namely that nearest to the head, we should in the first case (*fig.* 332.) have a descending current, and in the second (*fig.* 333.) an ascending; a proof that the distinction between the descending and ascending currents is not in reality due to any difference of the smallest importance, since one or other direction may be obtained according to the position that is given to the same muscle. We may remark further, that when the points of contact of the muscle with

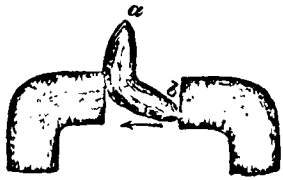

Fig. 333.

the cushions belong on both sides equally to the red muscular flesh solely, there is no current, or at least there is but a very slight one.

It would seem to follow, at first sight, from the experiments which precede, that there exists an heterogeneity between the tendon and the muscular fibre properly so called; but we are about to see that this is not the case, and that the tendon simply plays the part of a conducting covering inactive by itself. In fact, if after having hardened, in hot water or in diluted alcohol, a gastrocnemian muscle or an extensor muscle of the leg, we produce in it a longitudinal section by tearing or cutting it in the direction of its fibres, we perceive that the tendinous covering, the tendon Achilles for example, does not extend beyond the points where the extremities of the elementary muscular fibres are attached, which shows us that the tendon may be considered as the natural covering of the transverse section of the muscles, or as a surface formed by the reunion of the bases of the fibres considered as cylinders or as prisms. The red muscular flesh may, on its part, be regarded as the natural longitudinal section, or as a surface formed by the sides of these fibres considered as cylinders or prisms. Then, in order to explain the effects observed, we have merely to assume that the two surfaces of the muscle (the longitudinal and the transverse) are heterogeneous, the tendon being considered as a covering of the natural transverse section,—simply a conductor, and indifferent in an electrical point of view.

Experiment entirely confirms this mode of viewing it. Thus the artificial section that is obtained by cutting a muscle transversely, with a pair of very sharp scissors, behaves exactly like the natural transverse section covered with the tendinous membrane. In fact, no current, or a current that is scarcely sensible, is obtained upon placing between the cushions the middle part of a muscle terminated by two artificial transverse sections, whilst a very decided effect is obtained by placing in contact with the cushions on one side an artificial transverse section, on the other the longitudinal section (*fig.* 334.), the current being always directed in the

muscle from the transverse to the longitudinal section. An artificial longitudinal section, obtained by cutting the muscle in the direction of the fibres behaves itself also like the natural section; so that we may sum up the law of the muscular current by saying that *each point of the natural or artificial longitudinal section of a muscle is positive in respect to the points of the transverse section, whether natural or artificial.*

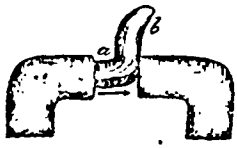

Fig. 334.

On studying the electric relations of the different points of a same section in relation to each other, we find, as well when this section is artificial as when it is natural, that the points which are nearest to the centre when referring to the transverse section, and nearest to the middle when referring to the longitudinal, are negative with respect to those which are the more distant from those points. This is proved, for the latter case, by placing the muscle (*fig.* 335.) so that it rests by its longitudinal section on the two cushions equally, but taking care that one of the extremities of the muscle (the extremity *a*, for instance) is nearer to the cushion than the extremity *b*; a feeble, but still a very decided current is thus obtained, travelling in the muscle from *a* to *b*. For the case of the transverse section, the muscle of a rabbit (the triceps femoris) must be taken, that of a frog being too small for this experiment. Care is taken to produce the section of the muscle with an instrument that cuts well, so as to obtain a very clean surface; then the different points of this surface are touched with the extremities of two auxiliary cushions, cut sloping and very pointed, and communicating, like the others, with the extremities of the galvanometer, and which are constructed and moistened in the same manner (*fig.* 336.).

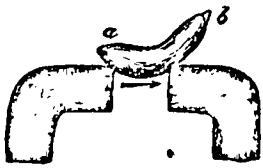

Fig. 335.

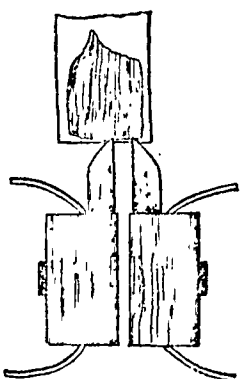
Fig. 336.

Moreover, the currents that are obtained on placing in

communication two non-symmetrical points of a same transverse or longitudinal section, are much more feeble than those that result from the communication established between the two sections.

The law of the muscular current, such as we have just established it, is general; M. Dubois-Reymond has proved that it is not confined to some species of animals alone. He has verified it on the muscle of the amputated leg of a man, on the muscles of the rabbit, of the porpoise, of the common mouse, of the pigeon, of the sparrow, of the tortoise, of the lizard, of the adder, of various species of frogs, of the toad, of terrestrial and aquatic salamanders, of the crab, and even of the earth worm; for this latter it sufficed to take for muscles entire fragments of its body.

It is now easy to see that the elementary law of the muscular current, such as it has been established by M. Dubois-Reymond as far back as 1843, explains perfectly well more complex phenomena and laws, discovered by Matteucci * both anterior and subsequently to this period, and in particular that of the current proper of the frog, which is nothing more than a particular and very remarkable case of the current that results from the communication established between the longitudinal section of the gastrocnemian muscle and the transverse section, covered in this case by the membrane forming the tendon Achilles, and particularly developed in the leg of the frog. Indeed the gastrocnemian muscle, like the triceps muscle of the frog, presents natural transverse sections where the muscular bundles abut on the tendons, the aponeurose muscles being then only coverings of these natural transverse sections.

M. Dubois-Reymond has compared, in respect to the energy of the muscular current, the different muscles with

* The law, established by M. Matteucci, that the current always travels in a muscle from the interior of this muscle to its surface, is in fact only the consequence of that more elementary law, subsequently established by M. Dubois-Reymond, that the current travels from the tranverse to the longitudinal section in the muscular fibre. There are even cases, as when the muscles of the heart are under consideration, in which M. Matteucci's law and that of M. Dubois-Reymond are found to be identical, as we are about to see immediately.

each other; and he has found that the current is the more intense in proportion as the muscle is intended to exert a greater mechanical action, and as this action is voluntary or involuntary. Thus the bundles of the heart, which are not subject to the empire of the will, manifest an energetic current, as do the muscles intended for the life of relation, which are all made to obey the will, whilst the muscular bundles of the intestines show a very feeble current, as having to exert only feeble mechanical actions. M. Matteucci was the first to demonstrate the electro-motive power of the muscles of the heart, by operating with a pile of pigeons' hearts cut transversely. M. Dubois Reymond operated upon the isolated hearts of frogs, of porpoises, and of domestic mice; and he observed that their artificial section is negative in respect to their exterior surface. Intact hearts also produce strong currents; and the extremity of the heart then represents the transverse section.

The existence of the muscular current being once well established, it may be asked what is the cause of it? Is it the indirect result of the chemical action that accompanies respiration? Is it a more immediate consequence of the living organism? We shall return further on to this delicate question, when we shall have studied the various causes that may exert influence over the muscular current. But whatever may be the origin of this current, we may seek to know the relation that exists between its power and that of the currents produced by the ordinary sources of dynamic electricity. It is this question that M. J. Regnault has endeavoured to resolve by comparing the electro-motive force of a muscle with that of a thermo-electric pair — bismuth and copper (with a difference from 32° to 212° Fahr.) — taken as unity. When operating with suitable precautions* upon the gastrocnemian muscle of the frog, he found that the maximum of the electro-motive force was comprised between 5 and 4 thermo-electric units. The bundles of muscles of the

* Among other precautions, M. J. Regnault, in order to avoid secondary polarities, employs a concentrated solution of sulphate of zinc, with zinc electrodes, for closing the circuit, instead of a solution of ordinary salt, with platinum plates.

thigh of a frog, that has been employed constantly as a Matteucci pair in his muscular pile, presents a more considerable value; its electro-motive force is comprised between 9 and 10 units. These numbers are independent of the size of the animal, but vary in the same animal from one muscle to the other. This difference is manifested equally in warm-blooded animals. Thus, on taking from a rabbit three different muscles prepared very rapidly, M. J. Regnault found for the electro-motive force 7 to 6 units for the gastrocnemian muscle, 11 to 10 with that of the leg, and only 6 to 5 with the biceps. He confirmed numerically the fact already pointed out, that more time is necessary to the electro-motive force of the muscle of the cold-blooded animal than to that of the muscle of a mammifer, in order to fall to the same degree of weakness.

Theory of the Muscular Current; Influence of various Causes, and in particular of Contraction, over the Intensity of this Current. — Induced or Secondary Contraction.

As the result of a very great number of experiments as delicate as they are difficult, M. Dubois-Reymond has succeeded in demonstrating that the electro-motor element in the muscle is each elementary fibre; he succeeded indeed, with the dexterity for which he is distinguished, in obtaining a current of 8° or 10°, by means of a simple elementary bundle, arranged so as to place the transverse and longitudinal sections in communication by means of the cushions of the apparatus. This point being established, what arrangement must be ascribed to the constituent parts (that is to say, to the organic molecules of the elementary bundles) in order to explain the effects observed? In order to obtain an idea of this, M. Dubois-Reymond conceives that we may form an image — a rough one, it is true, but still sufficiently resembling the elementary bundle, in comparing it to a cylinder of copper covered on its curved surface with a layer of zinc, its two bases remaining pure copper. This cylinder, plunged into a conducting solution, will give rise to a quantity of currents, which will set out from the different points of the surface of

zinc, in order to abut upon those of the two copper bases. Now, on establishing a communication, by means of a conducting body, between a point of the longitudinal surface of the zinc and a point of the transverse surface of the copper, a derived current will be obtained altogether analogous to those, that are obtained upon causing the longitudinal and transverse sections of a muscle to communicate. We may even explain how a current is obtained on touching two dis-symmetrical points of the same section; for it is easy to see, even with the metallic cylinders of which mention has just been made, that the currents which circulate from the different points of the surface of the zinc to those of the surfaces of the copper of the bases are not all equal, and that the iso-electric curves, or curves of equal electric tension, may be determined. Hence, with the cylinder as with the muscle, signs may be obtained of the current, much more feeble, it is true, than in the fundamental case, by touching points of the same surface that do not correspond with the points of an iso-electric curve.

Each isolated fragment, or each elementary fibre of a muscle, may, then, be assimilated to the cylinders of which we have just been speaking; and the currents that it furnishes to us, like those of the cylinders, are only derived currents, consequently much more feeble than the currents that actually circulate through the conducting matter of which it is composed. In order, now, to explain this electric state, we must admit that each organic molecule of which the muscular bundle is composed is naturally electric, and that it possesses the two electricities in the free state. M. Dubois-Reymond conceives that these molecules, which may be of any form, but which he supposes to be spherical, have each a positive equatorial zone, and two negative polar zones. He supposes, moreover, that they are so arranged, that the diameters which pass through the negative poles of each are parallel to each other and to the axis of the muscular bundle; he terms these molecules *peripolar*. We are disposed to believe, still adopting the analogy, in an electric point of view, of the muscular bundle with the copper cylin-

der covered with zinc on its curved surface, that it may be very well explained by assuming that the organic molecules have but two electric poles, one positive, the other negative, —an hypothesis that we have already set forth for inorganic molecules; only, on the other hand, we are led to suppose, as indeed M. Dubois-Reymond is obliged to do, in order to explain the electric phenomena of the muscle, that, by the effect of life, these molecules assume a peculiar arrangement. They are not, indeed, arranged as in an inorganic substance abandoned to itself, so that there is established an electric equilibrium by the effect of the mutual neutralisation of all the molecular electricities, but so that, in each transverse section of the muscular bundle, the positive poles of the molecules are turned outward, and the negative poles inward. The positive and negative electricities of the molecules of each section, which radiate from the centre to the circumference, neutralise each other, except the positive of those which are at the circumference, and the negative of those which are at the centre. But these two free electricities are reunited by the exterior surface of the muscle, forming currents perfectly similar to those which are established upon the moist surface that covers the copper-zinc cylinder, and of which we collect only a derived portion in the experiments, in which we cause the transverse and longitudinal sections of a muscle to communicate together, or two dis-symmetrical points of the same section.* Such, then, would be the arrangement of the molecules in each elementary muscular bundle, whence would naturally result a negative electric state to all the points of the two bases or extremities of the complete muscular bundle, and a positive state to all the points of the longitudinal surface. The electric state of the artificial

* The arrangement that we assume to be imparted by the effect of the vital principle, to the molecules that constitute the muscular fibre, would appear to us to agree in a remarkable manner with the supposition that we have made (Vol. II. p. 49.), that the electric polar state is due to a primitive movement of rotation that each atom of matter possesses, around an axis, the two poles of which are, one positive, the other negative. We might indeed conceive that the vital principle would act by compelling the molecules, of which a fibre is constituted, so to arrange themselves that their movement of rotation is accomplished in all in the same direction around the axis of the bundle.

sections, whether transverse or longitudinal, would evidently be also the consequence of the same distribution of the particles. We shall see, in a moment, that the hypothesis which we have just been laying down on the mode of arrangement of the organic molecules in muscular fibre, finds a remarkable confirmation in the phenomena, that result from the action of the various causes, that modify the muscular current.

Thus, then, whatever be the manner, in which we regard the arrangement and the part played by the organic molecules in muscular fibre, we may conclude, almost in a certain manner, from the study that we have been making, that the electric state of the muscles is that of a closed circuit, and that the current, which is collected either by the galvanometer or by the galvanoscopic frog, is merely a derived current, the intensity of which is much more feeble than that of the principal muscular current.

Moreover the analogy, that we have established between the muscle and an electric circuit, finds a confirmation in the fact observed by M. Dubois-Reymond, that the electro-motive force of muscles increases with their width and with their thickness. He has not found that the extension or the compression of a muscle exercises a very sensible influence over the muscular current; and he attributes the small diminution that he has sometimes observed as being exercised by these actions over the intensity of this current, to the alteration which they cause the vital force of the muscle to undergo.

Indeed the decrease that is suffered by the muscular current, setting out from the death of the animal, or from the moment when the muscle has been detached from its body, is a very important point to notice. M. Matteucci had observed that this decrease is the more rapid in proportion as the animal occupies a higher rank in the scale of beings; M. Dubois-Reymond attributes this difference to the fact that warm-blooded animals, mammifers and birds, lose their muscular irritability after death much more rapidly than fishes and reptiles. Now, according to him, the diminution in the intensity of the muscular current after death, is pro-

portional to the degree of excitability of the muscle; and the electro-motive force, as well as this excitability, have for their termination the rigor mortis, which arises, as Brücke has demonstrated, from the coagulation of the fibrine contained in the muscles outside the blood-vessels. It follows therefore from this, that the phenomenon of the muscular current should be considered as a phenomenon which can only take place in a living organic tissue, and which, when once it has disappeared by rigor mortis, cannot again be produced even when this rigidity has ceased, and when consequently decomposition has commenced,—a further proof that muscular electro-motive force is very dependent upon the arrangement that vital force imparts to the organic molecules in the structure of the muscle,—an arrangement that endures for some little time after the death of the animal, as well as does irritability, but which disappears as soon as (decomposition commencing) the particles no longer obey the forces that rule over organic matter.

But, of all the causes that may exercise influence over the muscular current, the most important, without contradiction, is the contraction of the muscle itself,—a contraction that is brought about by nervous irritation, namely, by imparting to a motor nerve, by physical, mechanical, or chemical means, that particular state which is manifested by the contraction of the muscle. Of all these means, the most efficacious is the transmission of an electric current through the nerve,—a transmission that may even produce tetanus, namely, a continuous contraction, itself taking place by a series of oscillations or intervals very near to each other: we have already seen this in the Fourth Part of this Treatise.* But the employment of an electric current in order to bring about muscular contraction, requires many precautions when we desire to study the influence of this contraction over the muscular current itself; for we must avoid with great care the influence exerted directly over this current by the electricity employed only as a means of obtaining the contrac-

* Vol. II. p. 512. *et seq.*

tion. It is under this relation that the method which M. Dubois-Reymond employed appears to us eminently calculated to give results secure from every objection.

A gastrocnemian muscle of the frog is placed (*fig.* 337.)

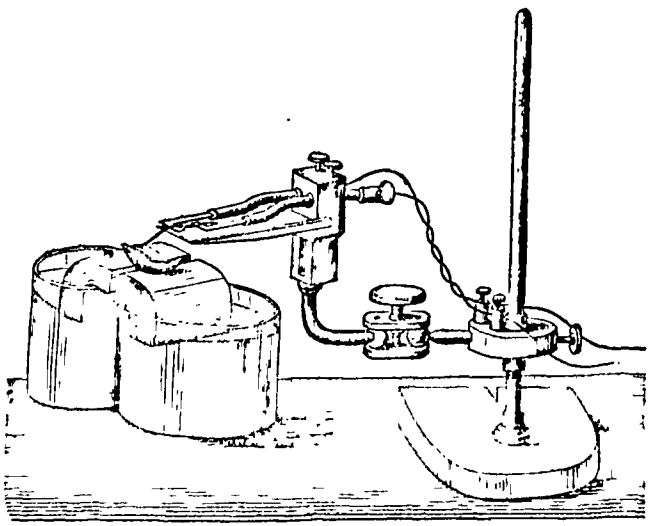

Fig. 337.

upon the ordinary cushions so that its nerve rests upon two small platinum plates, which it unites like a bridge, and which, being bent at a right angle, are each soldered by one of their extremities to a brass rod; these rods traverse with good friction a piece of ivory, that serves to insulate them, and at the same time to fix them; and they are capable of being set in motion so that the plates may be arranged according to the requirements of the experiment, and in particular as they are arranged in the figure. Conducting-wires, communicating with the rods, permit of placing the portion of the nerve comprised between the two platinum plates in the circuit of an electric current of any nature. A small glass plate, upon which the platinum plates rest, serves to prevent all possible contact between the plates and the gastrocnemian muscle.

The current that M. Dubois-Reymond employed in the experiments in question was an induction current, produced

in one of the wires of a bobbin by causing the current of a Grove's pair, very feebly charged, to pass by intermittence to the other wire. The passage of these induced currents through the portion of the nerve comprised between the two platinum plates, produces in the muscle a tetanic contraction, which is accompanied by a sudden change in the direction of the muscular current, then by an oscillation of the needle, which is unable to fix itself in a position of equilibrium so long as the tetanic state endures. This effect is in no degree due to a derivation of the current, transmitted through the nerve, coming and affecting the galvanometer; for, besides its being impossible to comprehend this derivation in the arrangement of the experiment, it is easy to prove that the same effect is not obtained by substituting for the nerve a wire or a band of moistened paper, which are better conductors than itself, and which, communicating with one of the extremities of the muscle, are placed in the same manner, that is to say, as a bridge between the two platinum plates. Moreover, the phenomenon that is observed when the nerve is excited by the electric current is likewise manifested, but only in a little less decided manner, when tetanus is brought about, either by irritating the nerve by chemical or mechanical action or by heat, or by poisoning a frog by strychnine.

The effect that we have been pointing out is not due, as one might suppose, to the production, by tetanic contraction, of a current contrary to the natural muscular current, but simply to a weakening of the current that results from it,—a weakening which permits the current arising from the secondary polarities to manifest itself. In order to prove this, we have merely to close the circuit of the galvanometer that indicates the presence of the muscular current, before the muscle has been tetanised, which enables us to avoid the production of secondary polarities; but if we close this circuit while the tetanic contraction is taking place, we then obtain a current moving in the direction of the muscular current, but only much more feeble than when the muscle has not been tetanised. This weakening does not arise (as M. Dubois-Reymond satisfied himself by direct experiment) either from an

increase in the resistance to conductibility, or from a defect of contact with the cushions, which might occur to the muscle from its state of tetanisation.

Instead of employing the galvanometer multiplier, we may use, for appreciating the influence of contraction upon the muscular current, the galvanoscopic frog. It is even easy to employ the two species of galvanometers at the same time, by arranging the experiment as is indicated by *fig.* 338., in which

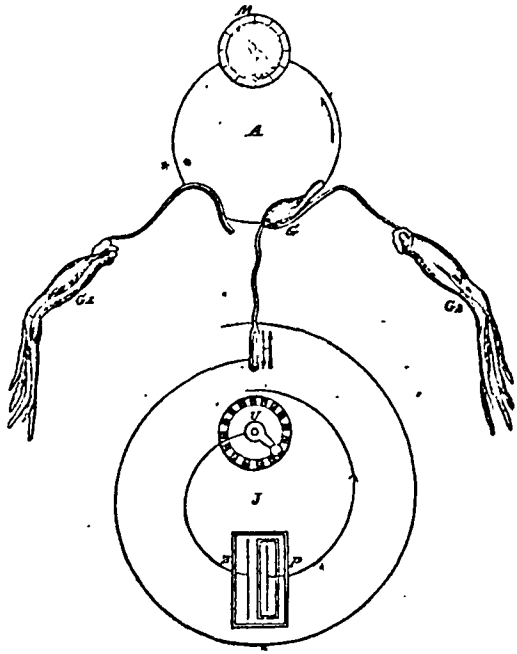

Fig. 338.

U represents the wheel employed for making the primary current J, produced by the pair $Z\,P$, discontinuous, whilst the induced current passes through the nerve of the gastrocnemian muscle G, the current of which is transmitted through a portion of the nerve of a galvanoscopic frog G_1, and through the galvanometer M. But if we wish to do without the galvanometer, we may apply the nerve of the galvanoscopic frog, G_2, directly upon the gastrocnemian muscle, G; this latter mode of operation was pointed out for the first time by M. Matteucci, in the production of the phenomenon

designated under the name of *induced contraction.* In the former method we see at the same time the thigh of the galvanoscopic frog contract tetanically during the whole time that the gastrocnemian muscle is itself tetanised, and the galvanometer moves as in the preceding experiment, but with less force, because the interposition of the nerve diminishes the conductibility of the circuit. But it is necessary, in order that this contraction of the galvanoscopic frog may take place, that the gastrocnemian muscle shall be so arranged upon the cushions as to give rise to the ordinary muscular current, namely, so as not to rest upon them by symmetrically situated points of the longitudinal or transverse sections; for in the case in which this muscle should be resting by symmetrical points, and in which consequently there would be no current, its tetanisation would not determine any contraction in that which is employed as a galvanometer.

We have said that the mode of operating, which consists in placing the nerve of the galvanoscopic frog in contact with the gastrocnemian muscle, had been discovered by M. Matteucci; the following is the mode in which he had been led to it by the production of the phenomenon described by him under the name of *induced contraction.* The learned Italian philosopher, after having prepared a frog in the ordinary manner, placed upon the thighs of this frog, so as to unite them as if by a bridge, the nervous filament of the galvanoscopic frog, taking care that this filament was not stretched; then, causing a voltaic current to pass into the lumbar nerves of the first frog, he brought about a powerful contraction in the muscles of these thighs: but at the same time he saw the galvanoscopic leg contract, the nerve alone of which was in contact with the thighs of the frog in contraction. This experiment, repeated by placing the nerve of the galvanoscopic frog upon the muscle of the thigh of a rabbit, which was likewise made to contract by means of the current that traversed its nerve, was varied in a thousand ways by its author. Thus he satisfied himself that, on irritating the lumbar nerves of the frog by means of pincers,

or of any body, he obtained, provided the contraction was sufficiently powerful, the induced contraction in the galvanoscopic frog. But it was not brought about by producing all possible movements upon the surface of the muscle upon which the nerve was placed, if these movements were not contractions.

He had again remarked that, on interposing between the galvanoscopic nerve and the muscular surface in contraction a plate of gold, or even a very thin plate of an insulating body, no effect was obtained, which had caused M. Becquerel to suspect that the induced contraction was due to an electric discharge emanating from this surface and traversing the nerve,—an idea that seemed to be confirmed by the fact that, when the nerve is separated from the muscle only by a band of moistened paper, the induced contraction is obtained, as it is when it is immediately in contact. All these effects are very well explained by derived currents, which do not traverse the nerve when the parts of the muscles upon which they circulate are insulated from it or united by a very good conductor, such as a plate of gold. However, M. Matteucci having thought that he perceived that the interposition of liquid masses, even apparently the most insulating, such as the essence of turpentine*, did not (like a plate of gold or of mica) arrest the production of the phenomenon, did not think that he could yet decide upon its nature in a definitive manner. He confined himself, by operating upon other animals besides the frog, such as dogs and rabbits, to prove this important fact,—that the phenomenon of induced contraction belongs only to the muscle in contraction, and in no degree arises from the action of the nerve that is excited in order to bring about this contraction.

* It is probable that the *liquid* strata which M. Matteucci employed were not so insulating as he thought them, because the liquid of which they were formed was more or less mixed with the animal liquid with which the muscle is always covered; otherwise, how are we to explain that excessively thin plates of mica, sulphate of lime, glued paper, leaves of vegetables, arrest the action, whilst it is not arrested by a layer of oil or of any other insulating liquid? This difference between the effect of the solid layer over that of the liquid one can only arise from the cause that we have pointed out; moreover, this is what M. Dubois-Reymond has demonstrated by direct experiment.

It is true that subsequently, and after having become acquainted with the researches of M. Dubois-Reymond, the learned Italian philosopher had adopted in a positive manner, basing it upon certain new observations, the idea, which he had not advanced without some reserve; that induced contraction might very well be due to an electric discharge, a little analogous to that of a Leyden jar, operating from one part to the other of a muscle in contraction, and of the same nature as that, which takes place in electric fishes.

M. Dubois-Reymond appears to us to have very well demonstrated that induced contraction, which he calls *secondary*, is only one of the forms under which is manifested the variation of intensity that the muscular current undergoes under the influence of contraction. He even succeeded, as did likewise M. Matteucci, in exciting, in a third prepared frog, a contraction identical to that which the first brings about in the second, by arranging the third in respect to the second, as the second is in respect to the first. M. Matteucci extended the experiment even to contractions of the fourth order; and M. Dubois-Reymond even to those of the fifth. The essential point to which his preceding researches had taught M. Dubois-Reymond to have regard, is always to place the two points of the nerve of the frog that is to suffer muscular contraction upon points as dis-symmetrical as possible of the muscle in contraction; no effect is obtained when the nerve is made to communicate with two points situated symmetrically.

The employment of the galvanoscopic frog, in this order of phenomena, has the advantage over that of the galvanometer, of making us better to know what passes in the electro-motive action of the tetanised muscle. The mode of contraction that the galvanoscopic frog undergoes, allows us to observe that the contraction of the tetanised muscles, although permanent in appearance, is not so in reality; but consists in a very rapid succession of simple contractions, each corresponding to a successive diminution and increase in the muscular current, whilst the needle of the galvanometer, which, on account of its inertia, is unable to follow all these varia-

tions, only indicates a permanent diminution of this current, — a diminution which, when the variations are very great, may even change into a current moving in a contrary direction on account of the secondary polarities.

We may represent the oscillations that a current undergoes in a tetanised muscle by a curve, whose abscissæ, being proportional to the time, are excessively small in respect to the ordinates, which are proportional to the force of the current; whence it follows that it has the form of a comb, the teeth of which are turned on the side of the axis of the abscissæ without touching it; the heights of these teeth themselves represent the differences of length of the ordinates, or the differences of intensity, that the muscular current suffers between the instant of the contraction and that which immediately succeeds it. The modification that is suffered by the law of the muscular current from the effect of contraction consists, then, simply in this,— that, at the moment of this act, all the ordinates of the curve of the intensities of the muscular current undergo a reduction of their size proportional to their relative size. In other words, the magnitude of the negative action that accompanies tetanus is proportional to the primitive intensity of the muscular current, so that the negative electro-motive action of the contraction is observed the more easily, as the primitive intensity of the muscular current is more considerable. Thus, if this intensity is null, as when the extremities of the galvanometer are applied to the longitudinal section of the muscle, and at equal distances from the middle, the needle of the galvanometer does not move, even in the most active tetanus. This law is very important; and it is apparent that, in order to discover it, it would not be enough to cause the muscle to undergo a single contraction, but it would be necessary to make it enter into tetanus, in order to prolong upon the needle the electro-motive action, whether positive or negative, that we might suspect to emanate from the muscle at the moment of its contraction.

A very remarkable fact is, that secondary tetanus, namely, the contractions of the galvanoscopic frog, and consequently

the variations of intensity which they indicate in the muscular current of the muscle tetanised directly, may be produced by bringing about nervous irritation by intoxication by means of strychnine, as well as by the discontinuous electric current. However, it would seem that in this case, the source of direct irritation not being intermittent, as when this source is the discontinuous current, we ought not to obtain that rapid succession of contractions which, as we have seen, characterise tetanus. However, the phenomenon remains the same in both cases, and appears to possess analogy with the observations made by some philosophers upon the intermittent nature of the voluntary tetanic contractions of their muscles.

Among the other influences that may be exercised over the muscular current, we will point out also those of cold, and of various media that have been studied by M. Matteucci. With regard to cold, he has remarked that a prepared frog presented no contractions proper, nor deviations on the galvanometer, when it had been surrounded by ice for some minutes; but that it commenced to give them again when, after having been withdrawn from the ice, it was placed for some moments in water from 60° to 70°. As far as the influence of media is concerned, he found, on operating upon piles made with the thighs of frogs, that, with the exception of sulphuretted hydrogen and nitrous gas, the greater part of the other gases in no way influence the intensity and the duration of the muscular current. As the result of more recent researches, the learned Italian philosopher has proved a fact, that had been already pointed out by two other physiologists, namely, that the muscles of frogs recently prepared give rise to an absorption of oxygen, and to an exhalation of carbonic acid, and sometimes even to an exhalation of nitrogen. But what M. Matteucci was the first to recognise is that, during muscular contraction, the absorption of oxygen and the exhalation of carbonic acid increase by a quantity superior to double the absorption and exhalation observed under the same conditions for muscles in rest. He is likewise led to conclude, from his researches, that at the same time the

respiration becomes more active at the moment of the muscular contraction, there is a liberation of heat and electricity in the muscles; which confirms him in his opinion that these liberations are, both of them, connected with the electric phenomena of muscular respiration, and consequently have a cause inherent in muscular fibre in the state of life. Going on further, he endeavours, by calculating the quantity of mechanical work due to the excess of oxygen consumed by the muscles in contraction, to compare it with that of the effective muscular work found by experiment; and he found for ten gastrocnemian muscles of the frog 0·657 lbs. for the work calculated, and 0·577 lbs. for the effective work. This approximation between the animal machine and the steam engine, which has for its basis the recent theory of the mechanical equivalent of heat, appears to us a little forced, inasmuch as there exists in one of the machines, and not in the others, a principle, namely, the vital principle, the influence of which must render all comparison very difficult. We may add that M. Matteucci conceives that these experiments prove in a positive manner that the chemical action of muscular respiration during contraction generates the force developed in the muscles; and that probably this chemical action is first transformed into electricity, in order to produce the contraction. Moreover, he admits that in animal machines, as in those which are governed by heat or by electricity, the production of the force is subject to the same laws. We shall return to this point when we are occupied with the nervous force.

In all that precedes, we have studied muscular electricity and the causes that modify it on detached muscles, or on those belonging to animals recently killed, or at least mutilated. M. Matteucci had already made some trials, in order to prove in living frogs the phenomena that he had observed in frogs deprived of life; but the animal was not intact; it was always wounded in certain points. We are indebted to M. Dubois-Reymond for having succeeded in proving the phenomenon of muscular electricity in living animals, and particularly in man.

The muscular current of the frog is easily to be observed on the living but skinned animal; indeed, if we leave the skin upon its muscles, we find abnormal results, which are due either to the fact that the skin conducts the muscular current, or that it appears to possess an electro-motive force proper; in order that the muscular current may show itself in all its intensity, it is necessary that salt water be in contact with the natural surface of the muscle. There exists even, independently of the skin upon the surface of all the muscles of the frog, a superficial film, that acts more or less energetically, in respect to each muscle individually, in a contrary direction to the electro-motive force of the muscular current; and which, for this reason, M. Dubois-Reymond terms *parelectronomic*, in order to indicate that it is opposed to the manifestation of the laws of muscular electricity. It follows from this that, if we cause a muscle to communicate with the galvanometer by its natural transverse and longitudinal sections, the current observed is sometimes intense, but more frequently very feeble, or even in a contrary direction to the direction of the natural muscular current. The fall of temperature, on causing the muscular current to disappear, causes the inverse current, due to the parelectronomic film, to predominate. This state of the muscle, called in like manner the parelectronomic state, immediately disappears, and the normal muscular current is manifested if the parelectronomic film is removed, if it is moistened with salt water, or if it is destroyed by the contact of a piece of porcelain highly heated. The muscles of mammiferæ, of birds, and of fishes, present the same property. In order to observe the muscular current in the living animal, it is necessary, therefore, to guard against this cause of error; and for this purpose, we have merely to moisten with salt water the points of the skin of the frog, for example, what are to be put into communication with the galvanometer, by the intervention of the moist cushions.

The manner of manifesting the existence of the muscular current in man is more difficult. It is in the first place necessary to have an excessively sensitive galvanometer

(M. Dubois-Reymond employed one of 27,000 convolutions), on account of the great resistance that is presented by the human body, a resistance of which we have already seen an approximate value *, but which diminishes much when the epidermis is removed in the portion of the body placed in communication with the salt water that closes the circuit. This is not all; M. Dubois-Reymond has also found causes of error to eliminate in the currents, that may arise from the action of the skin at the points of contact, from inequality of temperature, from the want of simultaneity in the establishment of the contact of the two points placed in the circuit; finally, from the tension of the skin, variable according to the arrangement of the limb touched, — a state altogether independent of contraction. These four causes act as well when two dis-symmetrical points are touched in order to collect the muscular current, as when two symmetrical points are touched, which cannot give any muscular current. Finally, to these four causes is joined one which had been pointed out by M. Becquerel, and which M. Dubois-Reymond has actually found to be very energetic; it is the unequal transpiration of the points of the skin, placed in communication with the galvanometer.

After having analysed with care all these sources of electricity, in order to be able to eliminate or to take account of them, M. Dubois-Reymond has found that the most certain method of demonstrating the existence of the muscular current in the living man was not to collect it directly, which is almost impossible, but to cause it to be manifested by the influence that is exerted over it by contraction, — an influence that we have been carefully studying in this section. The following is the method in which we must then operate. The observer plunges the fingers of both his hands into two vessels filled with salt water, communicating with the galvanometer by the intervention of two plates of platinum deprived of all electro-motive force. When the needle has become very tranquil, he contracts all the muscles of one of his arms as powerfully as possible, taking care that this

* Vol. II. p. 491., and following pages.

contraction does not bring about any movement of the fingers plunged in the liquid. At this moment the needle of the galvanometer suffers an impulse, the intensity of which depends upon the strength and the skill of the observer, but the invariable direction of which indicates that the current travels in the contracted arm from the hand towards the shoulder. This effect can only be attributed to the negative variation or diminution that is suffered by the currents in the contracted arm; whence it follows that the current of the arm remaining at rest preponderates; for previously, when the two arms were at rest, their muscular currents destroyed each other on account of their symmetry. Thus the natural muscular current of the arms would travel in each of them from the shoulder towards the hand.

The result of the experiment is the same, whatever the conducting solution may be that is substituted for the salt water, which proves that the effect cannot be attributed to a particular action of the liquid upon the surface of the skin. It is likewise easy to satisfy oneself that the agitation of the liquid and the small movements of the hand are without influence. The elevation of temperature that would result from the contraction of the arm is too feeble to explain the production of the current, which, besides, ought to be determined in a contrary direction, if it arose from this cause. M. Dubois-Reymond has likewise shown that it is not due to a congestion of blood arising from the contraction; for, upon provoking one by direct means, even much more powerful than that which accompanies the contraction, no effect is obtained. Finally, there remained one objection, made by M. Becquerel, and which consists in explaining the production of the current, by a sudden transpiration of the contracted limb; but this cause, as follows from the analysis that has been made of it by M. Dubois-Reymond, would give a current determined in a contrary direction to that which is manifested. With regard to the fact pointed out by M. Becquerel, that a current is still obtained, more feeble it is true, when the arm is contracted, before placing it in the circuit, and the hands are not plunged

into the vessels of communication until some moments after the contraction has ceased, M. Dubois-Reymond demonstrates that it is not contrary to the hypothesis that nevertheless attributes the current to the effect of muscular contraction; for he has remarked that the negative variation of the muscular current persists in the muscles of animals some time after the contraction has ceased; and this persistence must take place with man as well as with animals. Besides, it may be directly proved by observing that if, after having caused the needle of the galvanometer to deviate by the contraction of the muscles of an arm, we allow these muscles to return to the natural state, the needle does not return to zero except with an extreme slowness.

Objections have been raised against the conclusions of M. Dubois-Reymond, that when an experiment is made with the frog similar to that which shows the existence of the muscular current in man, a reverse effect is obtained. Indeed, if a frog is placed astride by its lower muscles over the vessels of communication, no current is at first perceived; but if one of its muscles is made to contract, after having cut one of the sciatic nerves in order to paralyse the other, the galvanometer indicates a current that is descending in the contracted muscle, whilst it is ascending in the contracted muscle of man; as well when the muscles that serve to form the circuit are those of the feet as when they are those of the arms. This difference is very probably due to the very great difference that exists in the form and the arrangements of the muscular masses in man and in the frog. Moreover, we may recognise a similar opposition in the results in animals themselves. Thus matters occur in the rabbit as in man; and yet the laws of the muscular current are the same with the rabbit as with the frog and other animals. But the fact is, that there exists in the arrangement of the muscles of the frog, of the rabbit, and of man, an important difference, which perhaps explains the difference of the results. In the frog, at the upper extremity of the gastrocnemian muscle, the natural transverse section is, as it were, buried in the mass of the muscle, which causes that this muscle, in a state of rest,

can give only on ascending current; whilst in man and in the rabbit the muscular mass, which corresponds to the gastrocnemian of the frog, is terminated at its upper part by perfectly free aponeuroses, which causes that, in the state of rest, the muscle is able to produce a descending current in the exterior circuit.

We shall not terminate this paragraph without pointing out a means that M. Dubois-Reymond has employed for considerably augmenting the current produced by the voluntary contraction of the muscles, and which consists in removing the epidermis by means of blisters applied to the arm, and placing these artificial wounds in communication with the galvanometer. In this manner he has obtained a current of 60° or 70°; whilst, on causing the galvanometer to communicate with the same points of the skin remaining intact, he produced a deviation of only 2° or 3°, by the same contraction of the arm; which proves that the presence of the epidermis occasions the most powerful of the resistances, that are opposed to the manifestation of the currents of the human organism.

Of the Nervous Current.

The part played by the nerves in the production of animal electricity, regarded in the outset as very important, had appeared more recently, as the result of the multiplied researches of M. Matteucci, to be reduced to that of bodies simply conducting and participating in the electric state of the part of the muscle to which they were united. We have already seen that, even in respect to conductibility, the nervous substance is very inferior to the muscular tissue*, although the nerve, properly so called, is a little better conductor than the cerebral substance. But M. Dubois-Reymond has succeeded in demonstrating, by means of experiments carefully conducted and guarded against all objections, that there exist in the nerves, as there do in the muscles of living or recently killed animals, perfectly determinate electric currents. It is sufficient for this demonstration to

* Vol. II. p. 515.

take a fragment quite recently removed from the ischiatic nerve of a frog, and to place it upon the cushions so that it is in contact with them, on one side by its longitudinal section, on the other by an artificial transverse section (*fig.* 339.), and a current is immediately obtained, which may go as far as 25° or 30°, but generally only as far as 15° or 18°. This current, which finishes by producing a constant deviation of 5° or 8°, which is universally determined, as in the muscle, from the longitudinal to the transverse section, through the wire of the galvanometer. It is perfectly indifferent, for the direction of the current, whether it be one or other of the two transverse sections that is in contact with the cushion, the current always travels in the same direction (*fig.* 340.). If the

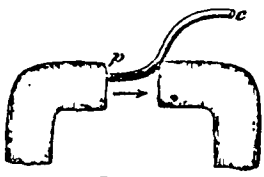

Fig. 339.

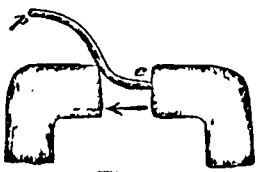

Fig. 340.

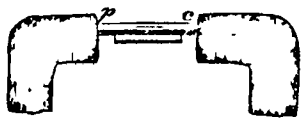

Fig. 341.

nerve is placed in communication with the two cushions, equally by both its transverse sections, being supported upon a little plate of glass (*fig.* 341.), the needle of the galvanometer is not moved; or if it manifests some slight deviations, either in one direction or the other, this is due to the difficulty there is in touching the cushions by the transverse section alone, avoiding all contact with the longitudinal section. The smallness of the transverse section prevents our being able to study the differences of the electro-motive action of its different points; but it is not the same for the longitudinal section; it is easy, as for the muscles, to place in contact with the cushions two dis-symmetrical points of this section, and we then obtain (*fig.* 342.) a current much more feeble, it is true, than when the circuit

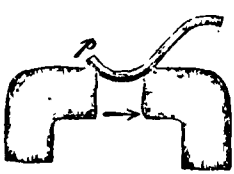

Fig. 342.

is closed by the transverse and longitudinal sections, but which, nevertheless, produces an impulse of 6° or 7°, and a constant deviation of from 2° to 4°. The direction of the current indicates that the points nearest to the middle of the nervous fragment are positive in respect to those which are nearer to the extremities. When the two points of the longitudinal section are at equal distances from the middle, there is no current.

The electric phenomena that we have been describing are the same in the nerves, whatever their nature may be, as well in the nerves of sensation as in the nerves of motion,—in the anterior as in the posterior roots,—in the mixed nervous centres as in the simple ones. The optic nerves of the frog being too small for this species of experiment, M. Dubois-Reymond took that of a fish, the tench, for example, and he obtained a current of from 40° to 45°, always directed from the longitudinal to the transverse section, through the wire of the galvanometer, in the brain, which presents no longitudinal section, properly so called; every artificial section is negative in respect to the points of the natural surface, which plays the same part as the longitudinal section. We may add that, in the same manner as when the muscular current is in question, the nerves of man, and of animals of various classes, all present the same phenomena.

M. Dubois-Reymond has succeeded in collecting the nervous currents by means of the galvanoscopic frog, as well as by employing the galvanometer multiplier. Indeed, we have merely to place the nerve of the galvanoscopic frog in the circuit of the nervous current, by employing an auxiliary cushion, placed between the other two, in order to see the frog contract by the effect of this current, in the same cases in which the needle of the galvanometer is deviated.

Thus the nervous current is subject to the same laws as the muscular current; we may therefore assimilate these two currents, and consider the former as being, as well as the latter, a derivation of the current that is established in

the nerves and in the conductors with which it is surrounded, by the effect of the electric polarity of the nervous particles, and of the arrangement which they assume under the influence of vital force. With regard to the electromotive power of the nervous particles, compared with that of the muscular particles, it is difficult to appreciate it; but we may affirm that, under equal circumstances, the nervous current is in no way inferior in force to the muscular current.

It is now of importance to know what becomes of the nervous current when the nerve is placed in that peculiar state which renders it fitted for conveying to the muscles, or to the nervous centres, those modifications that we recognise under the form of motion or sensation. The first thing to be done is, to find a means of placing the nerve in a state analogous to that which represents tetanisation in the muscle; this state, for the nerve of motion, is evidently that which produces tetanus in the corresponding muscle; and, for the nerve of sensation, that which produces the most lively sensation possible, of whatever its nature may be. We shall term placing the nerve in that state, *tetanising* it; and, in order to tetanise it, we have seen that the most simple means is to cause a series of interrupted currents to pass through a part of its length.

But, before examining the effect of tetanisation, it is necessary to study that which results from the passage of constant currents through the nervous fragment. For this purpose, we have merely to place the nerve (*fig.* 343.) so that it is in contact by its transverse section with one of the cushions, and by its longitudinal section with the other, whilst its prolongation goes on and rests upon the two platinum plates, so that the portion comprised between these plates is traversed by a constant current, to which they serve as electrodes. If the current of the pile has a similar direction to that of the nervous current which circulates between the two cushions, we

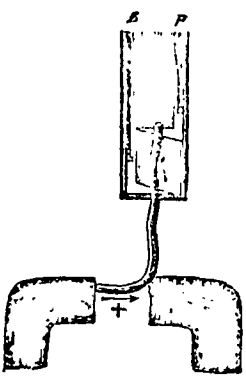

Fig. 343.

immediately see this latter increase in intensity; it diminishes if the directions of the two currents are opposed. These variations are maintained as long as the prolongation of the nerve is traversed by the voltaic current; they cease immediately that the latter is interrupted. There then evidently follows from the circulation in a part of the nerve of this foreign current, an alteration in the entire nerve itself; and it is this alteration that Dubois-Reymond has designated under the name of *electrotonic state* of the nerve. He distinguishes two different phases in this electrotonic state, — that during which the nervous current suffers an increase of intensity, and which he calls *positive;* that during which it suffers a diminution, and which he calls *negative.*

The two phases may be determined at the same time in the same nerve, by causing the artificial current to pass in a portion of the nerve taken in the middle of its length, and by causing each of its extremities to abut on the two systems of cushions, each united separately to a galvanometer by means of an arrangement similar to that represented in *fig.* 343. for a single extremity of the nerve. We then perceive, by the effect of the same voltaic current, that one of the two nervous currents, which goes in the same direction as the artificial current, increases in intensity, whilst the other, which goes in the contrary direction, is weakened.

We may add, that the phenomena are the more decided in proportion as the interval that separates the portion of the nerve placed in the circuit of the exterior current from the portion that is in the circuit of the galvanometer is smaller, as the exterior current itself is more powerful, and as the portion of the nerve submitted directly to its action is larger.

It follows, from the study of the phenomena that we have just been describing, and from the circumstances that favour it, that we may explain it by supposing that the electrotonic state which the nerve assumes is due to a molecular polarisation of the nerve, analogous to that which is

determined in all conducting bodies, by the effect of the passage of an electric current. This polarisation consists in the fact that the nervous molecules, endowed naturally, like those of the muscle, with two electric poles, turn all their positive poles on the side towards which the current is directed, and their negative, on the side whence it comes. We must only assume that this polarising action may extend with decreasing intensity, it is true, even to the portions of the nerve that are beyond the circuit of the artificial current. This explanation, which we borrow from M. Dubois-Reymond, does not require that we should admit, with this philosopher, in the nerve any more than in the muscle, the existence of peripolar molecules, which he supposes to be formed in the nerve, each from the juxtaposition of two bipolar molecules. We consider that it is enough to suppose that these molecules are bipolar; and that, under the influence of the vital principle, they are in the nerve, as in the muscle, arranged in such a manner that their positive poles are turned exteriorly, and their negative interiorly. This arrangement explains for the nerve, in the same manner as for the muscle, the manifestation of a current proper, called in this case nervous current, which takes place when a transverse section of the nerve is made to communicate with a longitudinal section. But, under the influence of the exterior current, the nervous molecules, more mobile than those of the muscles, may, in part at least, arrange themselves one after the other, according to the mode designated under the name of polarisation, and assume this arrangement, even in the portions of the nerve not traversed directly by the current. There results from this, the circulation in the nerve of a new current, which must increase or diminish, according to its direction, the nervous current itself.

If the current that is made to pass through the fragment of the nerve placed between the two platinum plates, instead of being continuous is discontinuous, and still better determined alternately in contrary directions,—cases in which tetanisation is produced, the part of the nerve placed in the

circuit of the galvanometer suffers a diminution in its current proper, whatever be the direction of the exterior current, whilst with the continuous current there is an increase when the current goes in one direction, and diminution when it goes in the other. The effect of tetanisation is consequently the same for the nerve as for the muscle. But it is of importance to know whether this effect still takes place when the nerve is tetanised otherwise than by the electric way; M. Dubois-Reymond has succeeded in proving that it is so; and for this purpose he has been obliged to employ a galvanometer of 24,160 turns. By means of this instrument —so sensitive, and consequently so difficult to manage—he has obtained a negative oscillation of the nervous current, when operating upon the nerve of a frog poisoned by strychnine,—a nerve that had been exposed from the ham to the vertebral column, and which was found to be tetanised by the effect of the poison. A negative oscillation of the nervous current, but of 1° to 3° only, is likewise obtained by burning and by bruising the free extremity of a nerve placed between the cushions, as it is arranged in *figs.* 339. and 340.

In order to know whether the negative oscillation of the nervous current, which is produced by tetanisation is continuous or interrupted, as in the muscle, it is necessary to substitute the physiological galvanometer for the galvanometer multiplier. With this view we place upon the platinum plates of the apparatus of *fig.* 343. a fragment of nerve, of which the rest remains resting upon a very dry plate of glass; then the circuit is closed by uniting, by means of a portion of the nerve of the galvanoscopic frog, the transverse and the longitudinal sections of the former nerve; through this nerve is transmitted a current, rendered discontinuous by means of a toothed wheel, placed in the circuit of a Grove's pair; and the secondary contraction is obtained in the galvanoscopic frog. In order to determine whether this effect arises from the negative variation of the nervous current, in the nerve traversed by the artificial current, as when the muscle is in question, or simply from the successive

appearance or disappearance in this nerve of the electrotonic state, M. Dubois-Reymond has tried with success to obtain secondary contraction, by simply placing beside each other the extremities of the nerve excited by the current, and of the nerve of the galvanoscopic frog (*fig.* 344.). It is not, then, necessary that the excited nerve should be in contact with the other by the longitudinal and the transverse sections at the same time, which seems to indicate that the secondary contraction is not actually due to the negative variation of the nervous current, but rather to oscillations of the electrotonic state. What confirms this conclusion is, that in order to obtain secondary contraction the portion of the principal nerve, which is beside that of the galvanoscopic frog, must not be too far from the portion submitted directly to the action of the exterior current, and it is necessary that tetanisation should be produced by the electric way.

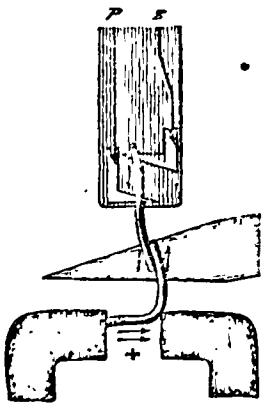

Fig. 344.

There is, then, an important difference between the muscles and the nerves, in respect to the cause of the secondary contraction, that results from their tetanisation, the effect being produced in the former by the negative variation of the muscular current which accompanies the contraction, and being independent of the cause of this contraction; whilst in the nerves it is connected with the appearance and the cessation of the electrotonic state, and consequently dependent upon the mode employed for exciting them, a mode which must be an electric current. We are unable therefore to decide, by the experiments that precede, the question—of knowing whether the negative variation is continuous or intermittent.

M. Dubois-Reymond has succeeded in demonstrating, by arranging the experiment as indicated by *fig.* 344., that the electrotonic state of the nerve, excited directly, determines also in the contiguous nerve an electrotonic state, but the

reverse of its own. He has even succeeded in producing the electrotonic state in a nerve by the effect of its current proper; with this view, after having arranged the nerve, as indicated by *fig.* 339., he tied the free extremity into a ring, so that the transverse section *c* was in contact with a part of the longitudinal section, situated beyond the cushions; there resulted from this a current circulating in the part of the nerve bent into a ring, and an electrotonic state indicated by the change of intensity of the current in the portion comprised between the two cushions.

All the experiments relative to the nervous current have been repeated upon nerves of different natures, and it has been proved that there existed no difference between them with regard to the effects observed,—that in this respect the nerves of motion and the nerves of sensation conduct themselves in the same manner. This observation has enabled us to solve the question of knowing whether, in each class of nerve, the irritation is only propagated in one direction,—from above downwards in the nerves of motion, and from below upwards in those of sensation; or, if it can be propagated in all nerves equally in both the opposed directions. Indeed, the question can be solved in the latter manner only, when once it is demonstrated that, whatever be the portion of any nerve that is tetanised, there is manifested a negative variation of the nervous current in the rest of the nerve, a proof that the irritation is propagated in all directions equally.

A last important observation, as far as concerns the electric state of the nerves, is also due to M. Dubois-Reymond. He had remarked that in warm-blooded animals it sometimes happens that the direction of their muscular current is inverted a very short instant before the moment when it disappears entirely by the effects of the loss of vitality. The nervous current presents a modification of the same kind, although not identical, when the nerve is wounded by either mechanical, calorific, or chemical actions. Thus, if a hot iron is brought suddenly near to a nerve placed upon the cushions, but without its being touched with this iron, the

nervous current is seen to change rapidly in direction, without however the property of the nerve of acting upon the muscle being destroyed; if the nerve is replaced in contact with the muscle so that it regains its natural humidity, it recovers at the same time its ordinary electro-motive power. However, it is easy to prove, by direct experiments, that this inversion of current is not due to an increase of resistance in the nerve, arising from its desiccation, by the effect of the radiant heat. A remarkable thing is that, when the nerve is in this abnormal state, all the transverse sections that are produced in it by cutting it are positive, instead of being negative, in respect to the longitudinal section.

Relation between the Muscular Current and the Nervous Current, and Physiological Consequences.

We may now regard as demonstrated in a decided manner, by the researches, that we have been describing: 1st.—That there exists both in the muscles and in the nerves of all animals a natural electricity, independent of mechanical, physical, or chemical actions, whether exterior or interior. 2nd.—That this electricity is manifested under the form of closed currents circulating along the muscles or the nerves of the animal, and of which we can collect but a very small derived portion, by the assistance of our instruments. 3rd.—That the presence of this free electricity is subordinate to the state of the life of the animal, and that it disappears with the vital force. These points being once attained, the following are in brief the laws that regulate the muscular and the nervous currents; they are the same except in a small number of very essential points, it is true, as we shall take care to make apparent.

1st.—In the nerves, as in the muscles, there is an electric antagonism between the transverse section, which is negative, and the longitudinal, which is positive, with this slight difference, that the nerves, having no natural transverse section, it is necessary to cut them, in order to collect their current, whilst this is not necessary for the muscles, which

possess two natural transverse sections. However, the electro-motive power of muscles that have not been cut is sometimes more or less disguised by the effect of the parelectronomic layer, which exercises a contrary electro-motive action. This action is recognised, in that it seems to increase by the effect of cooling, on account of the diminution that cold brings upon the muscular current, without altering that of the parelectronomic layer.

2nd.—The laws that govern the electric state of the muscles and of the nerves belong to each of the smaller parts, of which we may suppose them formed, that is to say, to their elements.

3rd.—The electro-motive power of the muscles and of the nerves does not endure after the death of the animal to which they belong, or after they have been separated from it, except so long as their susceptibility of being excited remains; a susceptibility which may disappear either gradually by the cessation of the conditions necessary to life, or by the sudden privation of their vital properties, by means of heat, of chemical actions, &c.

4th.—A sudden and great diminution is observed in the current of the muscle at the moment when contraction is brought about, and in that of the nerve when a motion or a sensation is transmitted.

5th.—The negative variation of the muscular current is not permanent, even when the contraction seems to be so, as in the state of tetanus; but it is composed of a rapid succession of simple and sudden variations of intensity. The muscular current does not recover its intensity immediately, but gradually, after the contraction has ceased.

6th.—The nerve differs from the muscle in its electric relation in that, when it is traversed in a portion of its length by a continuous current, the entire nerve assumes an electric state, which we have termed electrotonic, whence results the production of a current which, according to its direction, increases or diminishes the effect of the ordinary current. This electrotonic state of the nerve that may be imparted to the muscles, is a commencement of electrolysation; it brings

about a contraction both by rising at the moment when the circuit is closed, and by disappearing at the moment when the circuit is broken.

7th.—The electric phenomena are identical in the nerves of motion and in those of sensation; both of them transmit the irritation in both directions equally..

If now we compare together the facts, that we have described in the various paragraphs which precede those, that we have given in Chap. IV. of the Fourth Part of this Treatise, entitled, *On the Physiological Effects of Electricity*, we arrive at some remarkable conclusions.

We had observed that, when we act by a current upon the nerves of a living animal, there is, at the commencement of the experiment, a contraction of its inferior limbs and a manifestation of pain, as well at the moment when the circuit is established as at the moment when it is interrupted, and this whatever may be the direction of the current; but we are not slow in perceiving, on continuing the experiment, that at the end of a certain time, shorter in proportion as the current employed is more intense, there exists a difference between the effects, according as the current travels in one direction or in another, and according as the circuit is established or interrupted. When the current that circulates is direct, that is to say, is sent in the direction of the ramification of the nerve, its effect is limited to the contractions of the inferior muscles at the moment when the circuit is closed, and to a contraction of the muscles of the back, accompanied by a manifestation of pain, when the circuit is opened. With the current sent in the converse direction, it is the contractions of the muscles of the back and the manifestation of pain which take place when the circuit is closed, and the contractions of the inferior muscles when it is opened. There are, then, two periods in the action of the current upon the living animal; and we may sum up what characterises them in saying that, in the first, the current acts in all directions, either at the moment when it is established, as well as when it is interrupted; and that, in the second, it acts in the sense of its direction when it commences,

and in the sense contrary to its direction when it ceases. M. Matteucci has succeeded, by operating upon a rabbit, in confirming these results, already pointed out by Marianini, as we have seen in the Fourth Chapter of the Fourth Part.

Before going further, we may remark that, if the current is able to produce with pain contractions in the muscles of the back and the head, even when it does not act directly upon a nerve that ramifies into these muscles, and thus to bring about a motion by the electric excitation of the nerve above the excited part, this is due to an action called *reflex*, or of reflection, — an action which is itself due to the circumstance that the sensorial excitation of the nerve, upon which the current acts, brings about the contraction by the intervention of the nervous centre upon which it abuts. M. Matteucci has very well demonstrated this by cutting, in a rabbit submitted to experiment, the spinal marrow, either totally or in different points. When the marrow has been cut quite at its extremity, there is no longer any contraction upon any higher point in the excited nerve; in other cases, there is a contraction upon those of the muscles that are inferior to the point where the marrow has been cut.

We shall not return to the different phases, so well described by Nobili, presented by the action of the direct current and by that of the inverse current at the different periods of vitality of the nervous system; any more than we shall to the alteration that is brought about in the properties of the nerve by the prolonged transmission of the current, — an alteration which, when it does not cease at the same time as the current that has excited it by the simple effect of vital force, yields to the action of an inverse current. All these effects are connected with the constitution itself of the nerve, and with the properties that flow from this constitution, and of which we have made a study in the paragraph of this chapter, commencing at page 41. The alteration or the weakening that the excitability of the nerve undergoes, when it is traversed for a certain time by a continuous current, is still more decided when the current is discontinuous, so as to bring about tetanisation; it follows from this that in

order to make the frog afterwards contract, a more powerful current is necessary in the latter than in the former case.

The ligature of a nerve arrests the action of the electric current as it does that of other stimulants; only it is necessary that it be stronger when the stimulant employed is the current. When the ligature has been very tight, the nerve is found, in the points where it is tied, very thin and reduced at its neurilema; then, on cutting the ligature, we no longer succeed in exciting contraction by irritating the nerve above the point which has been tied. Poisons act differently one from the other. M. Matteucci has observed that the one which diminishes most the excitability of the nerve is hydrocyanic acid; with regard to narcotics, such as opium or nux vomica, they do not diminish the excitability of the nerve of the frog, except till the last period of the poisoning. M. Matteucci has likewise remarked that when the death of the animal has been brought about by an electric discharge, the excitability of the nerve by the electric current entirely ceases. But in this case, as in the preceding, the frogs do not lose the irritability of the muscular fibre; the electric current excites in them contractions when it is applied to them directly.

A very curious observation of M. Bernardi's is that which relates to the action of the *curare*.* Two perfectly similar frogs are taken; one is poisoned by inserting under its skin a small piece of curare; then, when at the end of five or six minutes it ceases to show signs of life, the piece of curare is withdrawn, and this frog is prepared, as well as that which has not been poisoned, according to Galvani's method. The current of a small voltaic pile is made to pass in a portion of the lumbar nerve of each of them successively; the muscles of the one that has not been poisoned are immediately seen to contract powerfully, whilst not the slightest sign of contraction is perceived in that which has been poisoned; but on applying the poles of the pile on the muscles, they both

* The *curare* is a remarkable poison, the effects of which have been studied by M. Alvaro Raynoso in a Memoir communicated to the Académie des Sciences, and on which M. Flourens has made an important Report.

equally suffer a powerful contraction, and even the poisoned frog preserves for a longer time than the other the property of suffering muscular contraction.

The experiments that precede, in showing to us the possibility of bringing about muscular contraction in a direct manner by the application of electricity to the muscles themselves without the intervention of the nerve, call us to examine the important question of knowing whether muscular fibre is by itself, independently of all external action introduced to its nerve, capable of contracting; or rather, if it is always necessary, in order to produce the contraction of the muscle, that its nerve shall have been previously irritated. J. Müller and Longet had found that when a nerve has been for some time separated from the central nervous system, it no longer excites contraction in the muscles on which it abuts, when its free extremity is irritated. M. Matteucci has obtained the same result by acting upon frogs that had been poisoned by a solution of the alcoholic extract of nux vomica, introduced into their stomach. However, the same current of eight or ten pairs which, applied to the sciatic nerve of these frogs, did not produce any effect, brought about a contraction in the muscle submitted to its action. More than this, Humboldt the first, and many others after him, have succeeded, by means of the electric current, in causing to contract pieces of muscular substance taken from any animal whatever, from which all the visible nervous filaments had been removed with the greatest care. M. Matteucci, on repeating this experiment, satisfied himself that this contraction takes place at the moment when the current commences to penetrate into the muscular mass, and at the moment when it ceases to circulate; and this, whatever may be its direction relatively to that of the muscular fibres. This contraction, which lasts for a moment only, seems to consist in a species of shortening of the fibres; and although the circuit remains closed, the fibre, shortened at the first moment, receives its form, and it is only when the circuit is interrupted that it is seen to contract anew, although more feebly than the first time. Thus, the electric current alone of all the excitants tried,

when it is applied directly to the muscles, is able to bring about their contraction without the intervention of nervous filaments.

This last fact seems to establish a remarkable analogy between the manner of acting of electric currents and that of the nerves, for producing muscular contraction. A nerve excited by any means whatever, and an electric current applied directly, act in the same manner upon a muscle. Is it not, then, probable that it is by a modification in its natural electric state that the nerve acts, when, by virtue of an excitation arising from the brain or from the muscle, or from an exterior cause, it produces motion or sensation? Let us endeavour to see if it is possible for us to render an account of this mode of action.

We know that the nerve possesses of itself a certain electrical state, which we have succeeded in determining; we know, moreover, that this electric state is modified by every excitation exercised upon the nerve. The muscle has likewise a natural electric state, which is modified every time there is a contraction. In the absence of excitation exercised upon the nerve, and of contraction produced upon the muscle, there must necessarily be established a certain electric equilibrium, which consists in the circulation of internal electric currents, in relation with the chemical phenomena that are accomplished in the living muscle. We do not wish to say by this that these phenomena are the cause of the electric currents; their cause is in the vital force which gives to organic molecules, naturally bipolar, the arrangement necessary for the establishment of this current; but this arrangement once established, the current is sustained by the chemical actions that accompany it, and which it probably determines itself in part.* Thus life is transmitted by the nerve by means of the electric state, that it possesses in the normal

* Vital force here plays a part analogous to that of the force which polarises the molecules of an electrolytic liquid, when a metal susceptible of being attacked by it is plunged into it; then, when the circuit is closed, the current itself is sustained by the chemical actions that result from the closing of the circuit; the latter at the same time increase in intensity. This takes place likewise for the chemical actions that constitute muscular respiration, since, as M. Matteucci has observed, they are more powerful when the muscle is contracted than when it is not.

condition of vitality; and from this there results for the muscle an analogous electric state, with certain differences to which we have directed attention, and which are due to the different nature of these two parts of the animal body.

Now if, by any cause whatever, the electric state of the nerve is modified, equilibrium is destroyed; and from this there results a contraction of the muscle or a sensation. Before studying the consequences of this modification we may remark, that it consists in the fact that the organic molecules of which the nerve is formed are not polarised transversely from within outwards, but longitudinally from one extremity to the other, as is every conducting body traversed by an electric current. When the modification arises from the immediate action of the nervous centre, it appears that the polarisation is brought about always in such a manner that the negative poles of the molecules are turned on the side of this centre, and the positive on the side of the muscle, as would result from the action of an electric current that might be travelling in the direction of the nervous ramifications. This it is that explains why an electric current, which travels in this direction, favours the contraction much more than when it travels in the contrary direction. This is equally a natural consequence of the fact that the particles of the nerves, upon which the immediate action of the brain must be exerted, being the interior which penetrate into it more deeply, have their negative poles free.

If, instead of coming from the brain, the action exerted upon the nerve comes from the muscle, the polarisation of the nerve must take place in a contrary direction, namely, so that the positive poles are all turned towards the side of the nervous centre, and the negative towards the side of the muscle whence the excitation comes. This reversion in the polarity of the muscles of the nervous filament that abuts on the brain must affect it, and produce in it a sensation. This is confirmed by the effect of a foreign electric current which, when it circulates in the nerves in a direction opposite to that of their ramifications, produces a sensation, and not a contraction. We conceive, therefore, from this,

that polarisation is established in a contrary direction in a nerve of motion, and in a nerve of sensation; and that the same nerve cannot at the same time, in the normal state, transmit motion and sensation. There is only the case in which it is excited in a part of its length; it may then transmit motion towards the periphery, and sensation to the nervous centre, its two portions being polarised in directions contrary to each other. The effect of ligature which, in altering the muscular constitution of the nerve, arrests the transmission of the cause of motion if it is made below the irritated point, and that of the cause of sensation if it is above, are equally well explained; for then the polarisation of the nervous molecules, under the action of the exciting cause, can no longer operate.

Now, how does the excitation of the nerve bring about the contraction of muscular fibre? Since we may bring about this contraction by the immediate application to the muscle of an exterior electric current, it is evident that the nerve brings it about by modifying the electric state of the muscle. We have seen that, when the muscle is contracted, its current proper diminishes, which appears to us to be evidently due to the fact that its particles change their place, and arrange themselves in respect to each other so that their negative and positive poles are turned in the direction of their length, as in a conductor traversed by a current, and no longer in the transverse direction. This change of place must produce an approximation of the particles in the longitudinal direction, and consequently a shortening of the fibre, which is the characteristic of contraction. But this shortening, and the approximation which is the cause of it, last only an instant, on account of the elasticity proper of the fibre, and the particles replace themselves at their former distance. However, there is an important difference to be noted. When muscular fibre is contracted by the effect of a continuous electric current applied either to its nerve or immediately to itself, the contraction endures, it is true, but for an instant; but the particles of the muscle, while still regaining, by virtue of elasticity, their former relative dis-

tance, preserve their electric poles turned in the direction of the length of the fibre; it is only at the moment when the electric current ceases to circulate that the electric poles of the particles replace themselves in their normal position, and this return is accompanied by a new displacement of the particles, and consequently by a new contraction. The reason why there is contraction only at the establishment and at the rupture of the current, is because it is only at these two moments that there is a semi-revolution of the particles of the muscle. When the current instead of being continuous is discontinuous, then there is so rapid a succession of displacements and returns to their primitive position of the particles of the muscle, that the contraction seems permanent, which constitutes tetanus; however, as we have seen, by means of the galvanoscopic frog, the contraction is really intermittent.

It remains now to know how it may result from a modification in the electric state of the nerves, that any particular muscle is modified so as to produce contraction. It would be necessary, in order to solve this question in a somewhat satisfactory manner, to know better than we do now the manner in which the nerves terminate, and in which they are ramified in the muscles. It appears to us probable that each elementary nervous filament abuts upon an elementary fibre*; then it is not astonishing that, if this nerve is polarised by a cause of excitation, it brings about the polarisation of the muscular fibre upon which it abuts; in this case the fibre enters into the circuit of the nerve, and it must suffer contraction, as when it is traversed immediately by an artificial electric current. We shall find, then, the same phenomena; in particular, that the contraction lasts but an instant, providing the nerve is not tetanised, which causes the muscle itself to be so also. In sensation it is the muscle,

* Doctor Waller has succeeded, by the section of nerves, in bringing about in the nervous filaments which are above the section an alteration that permits of following them into their last ramifications with a great precision; they are thus seen to penetrate even into the interior of the muscular fibres which they intersect. We regret that the limits assigned in a work of this kind to this class of considerations does not permit us to enter into further details upon the interesting researches of Dr. Waller.

whose normal electric state is disturbed, which polarises the nerve so as to act upon the brain. In both cases equally, it is not astonishing that everything which alters the molecular contraction of the nerve prevents its polarity being established, and consequently arrests the transmission of motion or sensation. It would be very important, in order to found these explanations upon more solid bases, and in order to be able to give to them more precision, that we should succeed in determining, better than has been done, the mode of communication of the nerve and the muscle. What appears to me eminently probable is, that in muscular contraction, as in the transmission of sensation, the reciprocal action of the nerve and the muscle is brought into operation at the very extremity of the nerve itself, and not all along its course through the muscle.

It follows, from the detailed study, that we have just been giving, that the body of a living animal may be regarded as the seat of an innumerable multitude of electric currents, the greater portion of them having only local circuits; it is the derived portions of these currents that we succeed in collecting by experiment. But when, by the effect of the will, or of another cause acting directly upon the nerve, its electric state is modified, the corresponding local current is transformed, if not entirely, at least in part, into a current, the more considerable circuit of which comprehends then the nerve and the corresponding muscle; and the effects, that we have been pointing out, result from it.

We shall not quit this subject without remarking, that we are led to assume that the agent, by means of which all nervous action is exerted is electricity; not an electricity created at the very moment when the nerve acts, but pre-existing in all the organic particles, as it pre-exists in all the particles of inorganic matter. We are, moreover, forced to admit that, under the influence of life, these particles are arranged in an altogether special manner, and which permits of the accomplishment of the organic functions; so that life cannot be considered as a consequence of the electric nature and of the arrangement of these particles, but must, on the

contrary, be regarded as the cause of their mode of grouping, and consequently indirectly of the phenomena that result from it. Let life indeed be taken away, and the particles, still preserving their electric properties — that is to say, their polarity, — are grouped quite differently, so as to obey the conditions of equilibrium of the forces that are proper to them, and no longer present aught but the ordinary phenomena that inorganic matter offers to us.

M. Matteucci, while still recognising that organic currents are not due to any exterior chemical action whatever, considers that we must attribute them to the chemical actions of living organism. It would be, according to him, in the chemical action that must exist between muscular fibre, properly so called, and arterial blood in contact with it, and consequently in the nutritive life of the tissues, that we ought to seek for the cause of these currents. It would be thus inherent in the state of the life of the organic tissues, and constantly connected with a difference in the state and in the nutritive power of these tissues, so that the positive element of the organic pair would be always represented by the part of the tissue whose nutritive power is the stronger. As is apparent, M. Matteucci agrees with us in this point, that it is from the vital force that he makes animal electricity depend in the first instance; only, according to him, it is only indirectly in compelling nutrition to operate that the nerves, intermediate between vital force and the muscles, would develop electricity, whilst, according to us, the action would be more direct; the transmission of vital action from the nerves to the muscles being brought about by the very electricity with which the nerves are primitively endowed. We shall in no way contest the part of chemical action in the production of animal electricity; but it is not from it that we make the first origin of this electricity proceed, which we think, as we have just said, to be pre-existent to the causes that determine its manifestation, as well in the living organism as when inorganic matter is in question.

Electric Fishes.

We have already indicated, in the first paragraph, that there exists a class of animals, the electric fishes, among whom the signs of electricity, the perception of which can take place in animals in general only under certain conditions, and with the assistance of very delicate instruments, are manifested in the most decided manner, and so as to have arrested the attention of observers from the most remote times. These fishes are five in number: the *raya torpedo* (the torpedo), the *gymnotus electricus*, the *silurus electricus*, the *tetraodon electricus*, and the *trichiurus electricus*. Of these five species two only have been carefully studied — the torpedo and the gymnotus; these are the two to which we shall essentially devote ourselves in this paragraph.

The torpedo, or electric ray, is the most anciently known of electric fishes, and the one which has been the subject of the greatest number of researches, seeing that it is easy to procure it, since it is found in the Mediterranean; its body, almost circular, is terminated by a short and very fleshy tail (*figs.* 345. and 346.); the space between the pectoral fins,

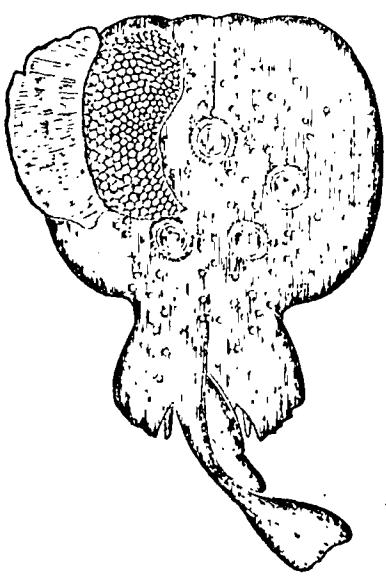

Fig. 345.

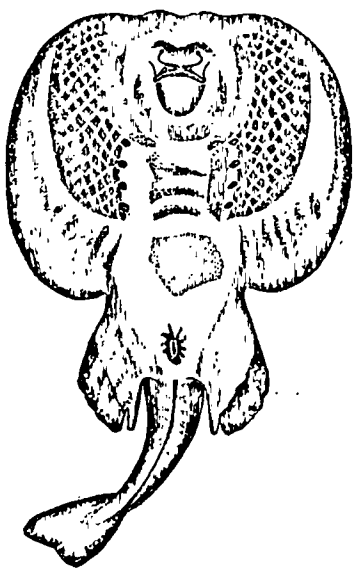

Fig. 346.

the head, and the gills, is filled on each side by an extraordinary apparatus, formed of small membranous tubes packed one against the other like the combs of the bee, subdivided by horizontal diaphragms into small cells full of mucus, and traversed by abundant ramifications of nerves arising from the eighth pair. It is in this apparatus that the electric power resides, as we shall see further on. The torpedo has been quoted from all times by fishermen as giving a shock voluntarily, either in order to defend itself, or in order to kill the fish necessary to its nourishment; but Muschenbroek is the first who established the electric nature of this shock. Walsh, in 1778, had made numerous researches upon this electricity; he had remarked that the shock is stopped by all bad conductors; and that consequently the torpedo can be touched with impunity with glass or resin, whilst shocks are received when it is touched with a rod of metal. He had succeeded in transmitting the discharge through a circuit of twenty persons, who held each other by the hand, and the last of whom touched the torpedo under the belly, whilst the first touched it on the back; he hence concluded that the back and the lower belly of the torpedo possess an opposite electric state. Gay-Lussac and Humboldt had more recently carefully described the principal circumstances of the discharge of the torpedo. But the first complete work made upon this subject is due to John Davy, the brother of the illustrious chemist, who, on placing respectively in contact with the two faces of the torpedo the two extremities of a wire, wound into a helix, or the two platinum ends of a galvanometer, succeeded in magnetising a steel needle, and in deviating the needle of the galvanometer. He had also succeeded in decomposing salt water, without, however, being able to obtain the effects of heat and light by the current of the torpedo, the direction of which he had thus determined, which he had found to be such that the upper surface of the fish is positive, and the lower negative. MM. Becquerel and Breschet, in confirming Davy's results, by experiments made in Venice in 1835, in which they had taken all necessary precautions to guard

against the different objections that might be made against the English philosophers' manner of operating, had established in an evident manner that the discharge of the torpedo is indeed the result of an electric discharge, analogous to that of the Leyden jar, and directed from the upper surface to the lower, at the same time that they had analysed the different circumstances due to the position and the condition of the animal, which may influence the intensity of its discharge. But, of all philosophers, M. Matteucci is the one who has made the most detailed and the most complete study of the phenomena, that are presented by the torpedo; also his are essentially the researches, which will guide us in the analysis, that we are about to make of the phenomena.

The torpedo effects its discharges in the air as in the water. When held in the hand, the discharges are so intense, and succeed each other with such rapidity, that it is impossible to endure them; but the animal becomes weary, and it is necessary to replace it in the salt water, and allow it a certain time of rest, in order that its electric function may be re-established. The shock that is darted by the torpedo is voluntary; it is brought about by irritating the animal in a point of its body, but especially by pinching the fins; more frequently it produces it spontaneously, either in order to defend itself, or to kill the small fish, which it thus shocks at a distance. M. Matteucci has shown the extreme diffusion of this discharge in the liquid in which it takes place; thus, on holding in the hand, in a large tub full of salt water, and 5 feet wide, and very near to its side, a living torpedo, we perceive, at the moment in which it discharges itself, a prepared frog, suspended in the same water, but at the opposite extremity, to become powerfully contracted; a proof that a portion of the discharge traverses it. A very powerful pile, under the same circumstances, would not produce the same effect.

The torpedo discharges itself *when* it wishes, but not *where* it wishes; it had been erroneously thought that it could direct its discharge, because the shock had been felt

on touching the torpedo in any point whatever; it is true that, if the discharges are powerful, they are felt everywhere that the animal is touched; but, when the latter is enfeebled, it is easy to see, on placing prepared frogs upon different points of its body, that it is only those which are on the points corresponding to the electric organ that are contracted. It is, moreover, necessary, in order that the frog, like any other conductor, may be traversed by the discharge of the torpedo when the latter is insulated, that it shall touch it in two different points of its body; if it touches it only by the extremity of its nervous filament, it suffers no contraction; it is no longer the same when the torpedo communicates with the ground; the frog then contracts, because there is established a very natural communication between a second point of its body and a second point of the torpedo.

M. Matteucci and Father Linari have succeeded in obtaining very decided electric effects with the torpedo; they have magnetised steel needles, as John Davy had already done; but Father Linari has, moreover, succeeded in producing a véritable electric spark between a surface of mercury communicating, by means of a conducting wire, with one of the surfaces of the electric organ and an iron wire communicating with the other; he has likewise obtained an inductive spark by causing the discharge to pass through an electro-dynamic helix. Father Linari is, therefore, the first who drew an electric spark from the body of a torpedo. He has also, with the electricity of the torpedo, decomposed nitrate of silver, and obtained calorific effects by means of a very sensitive thermo-electric element; finally, he has endeavoured to measure, by employing Becquerel's electro-magnetic balance, the intensity of the electric currents produced by the discharge of the fish. M. Matteucci has employed, in order to obtain signs of electro-chemical decomposition, a band of paper saturated with a solution of iodide of potassium, by means of which he established communication between two platinum plates, placed one on the back, and the other on the belly of the animal. The nature of the decomposition gives the direction

of the current, which is what we have already indicated, and which is confirmed by the more sensitive indications of a galvanometer. It is also M. Matteucci who has described the most simple and the most elegant manner of obtaining the electric spark; it consists in placing a torpedo, at the moment when it is withdrawn from the water, upon an insulated metal disc (*fig.* 347.), and covering it with another similar disc, held by an insulating handle; two brass rods, each communicating respectively with one of the discs, are terminated by balls A and B, to which are applied gold leaves, suspended at a distance of $\frac{1}{12}$th of an inch from each other; and on slightly agitating the upper disc, the animal is irritated; at the same moment the gold leaves move, and very brilliant sparks are seen to sparkle between them.

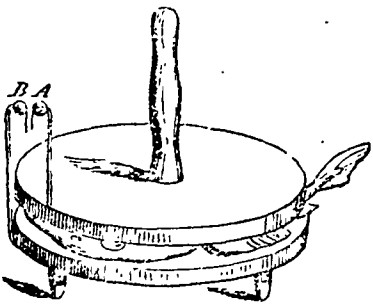

Fig. 347.

Before pursuing the study of the electric properties of the torpedo, it is necessary to return to the particular organ that exists in it as in the other electrical fishes, and the existence of which we have already pointed out. This organ, called by physiologists the *electric organ*, is not exactly the same in all electric fishes, as we shall see when occupied with the gymnotus. In the torpedo it is composed of two similar portions, symmetrically placed on each side of the head, between the pectoral and the brachial fins; they both occupy all the thickness that separates the two folds of the skin. Each of them is composed of a great number of prisms of an hexagonal form, ranged parallel one beside the other, as the cells of a honeycomb, and one of the extremities of which rests on the skin above, and the other on the skin below (*fig.* 348.): an aponeurotic membrane envelops externally all this system. These prisms are themselves formed

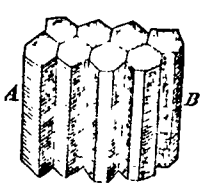

Fig. 348.

of a very great number of diaphragms perpendicular to the axis, separated from each other by very small intervals, filled with a liquid of an albuminous nature ($\frac{9}{10}$ of water, a little salt, and $\frac{1}{10}$ of albumen), and thus presenting a physical constitution analogous to that of a pile. Each diaphragm is composed of a very thin membrane, extremely simple, and without apparent structure, of a mean thickness of nearly 0·00015 in.; the space by which the diaphragms are separated from each other, and which is filled with the albuminous liquid, is about 0·000628 in. wide. From these data we are able to calculate that in a torpedo of mean size there are in each of the prisms of which its organ is composed, and which are $1\frac{1}{2}$ in. in length, 2000 diaphragms of 0·009 to 0·012 sq. in. of surface. Now as there are, according to Hunter, about 470 prisms or piles in each part of the organ, this makes for the entire organ 940 piles of 2000 diaphragms each.

To these anatomical details let us add an essential point: it is that four bundles of nerves of a large volume, setting out from the fourth lobe of the brain, arrive and distribute themselves in the organs in extremely numerous ramifications. The terminal ramifications of the nervous filaments do not abut directly on the diaphragms themselves, as Savi and Wagner had thought; but, according to M. Pacini, from whom we borrow these details, they enter into the albuminous liquid enclosed between two successive spaces; there they subdivide and apply themselves on the lower surface of each diaphragm; the one set are lost by their extremity in the substance of the diaphragm, whilst the others are terminated at the surface itself; the upper surface of the diaphragm does not receive any nervous fibre. It follows from this that the two surfaces of the diaphragms are in very different conditions of innervation, and consequently, no doubt, of electrical condition. Experiment also teaches us that the upper extremities of the prisms are all positive, and the lower, negative. If we cause two plates of platinum, communicating with the extremities of a galvanometer, to penetrate into the interior of the electric organ, we obtain, at the moment of the discharge, a current, which indicates that the part of the organ

nearest to the belly is always negative in respect to that which is nearest to the back; and this, whatever may be the part of the organ, in which the plates of platinum have been inserted.

Let us now examine more closely the circumstances that may modify or bring about the production of electricity in the torpedo. We should in the outset remark that the electric activity of the animal is proportional to the degree of intensity of its circulation and of its respiration; this is proved by the influence of temperature, of the ambient gas. The action of poisons, especially that of narcotics, brings about several very active discharges before bringing on the death of the animal; the discharge is also brought about by the exterior action of an electric current, that is made to pass from the mouth to the fins or to the skin, as well as by the irritation that is produced on compressing the torpedo in different points of the body. But, of all circumstances, the most important to study are those which act directly upon the electric organ itself, and upon the nerves that abut upon it.

In order to destroy the electric function of the organ, in acting upon its substance alone, it is necessary, after having removed the upper skin by which it is covered, to moisten it with sulphuric acid, or to place it in contact with boiling water. At the first moment, very powerful electric discharges are obtained; then, at the end of a few moments, the substance of the organ whitens and coagulates, and we can no longer draw from it any new discharges. Thus the coagulation of the albumen of the organ destroys its electric function, in whatever manner this coagulation is brought about. On the other hand, we may cut the organ itself, either horizontally or vertically, and introduce a plate of glass in order to separate the cut slices without the discharge ceasing to take place, so long as the albumen has not been coagulated.

Galvani and Spallanzani had already observed that, on cutting the nerves which abut upon one of the organs, the discharge ceases on the side on which this organ is, whilst it

continues on the opposite side. M. Matteucci has recognised that, in order entirely to destroy the discharge, it is necessary to cut all the four nerves, and not only one, two, or three. When two or three nerves are cut, the discharge is limited to the points of the organ in which the ramifications of the nerve, that has been left intact, are found. It is not necessary to cut the nerves in order to destroy the electric discharge; it is sufficient to tie them, and the same phenomena are observed. When the torpedo is very vivacious, we may obtain some electric discharges, even when the nerves have been cut, by drawing with pincers one of the nervous filaments that are attached to the organ; and even on detaching the organ with its four nerves, after they have been separated from the nervous centre, electric signs are observed on irritating sometimes one nerve, sometimes another. In order to perceive these signs, it is sufficient to place prepared frogs upon the surface of the organ, and the frogs are seen to contract upon the portion of this organ, in which the irritated nerve is distributed. The electric discharge may be obtained by a very small part of the organ detached from the living fish, upon the condition alone that the nervous filament, which goes to it, is irritated in any manner whatever. A piece of the organ which is not larger than the head of a pin, upon which has been placed the nerve of the galvanoscopic frog, never fails to give the discharge when it is cut with very fine scissors, and its nervous filament is thus irritated.

With regard to the brain, M. Matteucci satisfied himself, on exposing it very rapidly in a living torpedo with the blade of a razor very little sharpened, that the portion which cannot be touched without obtaining powerful discharges is the fourth lobe, which is as it were an enlargement of the spinal marrow elongated, and which is the one whence the nerves set out, that go to the electric organ. This lobe being destroyed, all discharge becomes impossible, even when the rest of the brain remains intact, whilst the other three lobes may be cut and removed without the discharge ceasing to take place; however, when they are irritated

powerful muscular contractions are produced, and sometimes even discharges, if the animal is very lively. But this is an indirect effect, similar to those which result from every exciting action exercised upon the electric fish. The essential organs of the electric function are therefore reduced to the last lobe of the brain, to its nerves, and to the organ properly so called; the action of this lobe upon the electric function is direct, that is to say, if we touch the right part of the electric lobe it is the right organ that gives the discharge, and reciprocally the left if it is the left part of the lobe that is touched.

When the torpedo upon which we operate is dead, at least in appearance, that is to say, when its gills no longer produce movement, and when irritated, wounded and squeezed, it no longer gives discharges, we obtain, on touching the electric lobe after the brain has been laid bare, more powerful electric discharges than those which the animal gave when alive; none are obtained on touching the other parts of the brain. But when a certain time has elapsed, we no longer obtain any discharge on touching the electric lobe; however, on wounding it, some discharges are still obtained, after which all electric phenomenon is for ever destroyed.

The electric current behaves as the other stimulating actions, that is to say, it does not produce the electric discharge except when it acts upon the fourth lobe, or upon the nerves which set out from this lobe to the organ. Its specific action differs only in this case, as in that of muscular contraction, from that of other exciting causes, in that its effect varies, within certain limits, with its direction, relatively to that of the ramification of the nerves. Thus, when an electric current is made to pass in a portion of the nerves of the organ, it is found after death that in a first period in which vitality is still very great, the direct or the inverse electric current always produces the discharge both at its establishment and at the instant of its interruption; but that in the following period, in which vitality is less, the discharge is no longer produced except by the establishment of the direct current, and by the interruption of the reverse current.

This last fact completes the analogies, which the study that we have just been making seems to establish between the action that determines electric discharges and that which produces muscular contraction. These analogies are indeed remarkable; thus, like muscular contraction, the electric discharge depends upon the will of the animal; it is in like manner brought about by an excitement produced upon certain nerves; it is proportional to the activity of respiration and circulation, although it may be obtained even when circulation is suspended in the organ; it endures only within certain limits of temperature; in a word, all the circumstances that modify the function of the electric organ act in like manner upon muscular contraction. The only difference is that the electric discharge, instead of being, like muscular contraction, a property common to all the muscular parts of the animal and of the nerves that lead to them, is specialised in a particular organ peculiar to the electric fish, to a determinate lobe of the brain, and to the nerves which pass from this lobe to the organ in which they are ramified; this lobe and these nerves have no other function, and in this resemble the nerves of sensation and the roots of the spinal marrow. Thus, all exterior action that is applied to the body of the electric fish, and in consequence of which the animal gives the discharge, is transmitted by the nerves from the irritated point to the brain, and thence to the electric lobe and to the nerves of the organ; it is a case of the reflex action, of which we have already spoken in the preceding paragraphs.

If, now, we compare the special phenomena that are peculiar to the electric fishes with the general phenomena that are presented by all other animals, and which we have described in the preceding paragraphs, we are led to conclude that the nerves which bring about the electric discharge must be identical in their natural state, and in the modifications which this state undergoes, to the nerves of motion which produce muscular contraction. The only difference is, that these nerves, instead of abutting on an ordinary muscle, abut on the peculiar organ that we have

called the electric organ; and that their electricity, instead of being converted into motor-action, is accumulated by the effect of the arrangement of the parts of which the organ is composed, so as to give violent shocks; in short, the organ, at the moment of the discharge, undergoes no change of form contrary to what takes place for the muscles. It is evident, from the experiments of M. Matteucci, that each cell, or each space comprised between two diaphragms, is the elementary organ; and that each prism, formed by the reunion of these elementary organs superposed, is as it were a pile, having at its extremities two poles of contrary natures, the charge of which is proportional to the number of elementary organs, which constitute the prism itself. But in order to obtain the charge of this pile, and consequently the discharge, it is necessary that the nerves which ramify into each cell should be irritated, for there is no electric effect in the parts of the organ where the nerves are not. This is proved in an evident manner by taking a living torpedo, and cutting the organ with a razor, parallel to the surface of the fish; we then obtain an internal surface upon which the large nerves are seen to be ramified; and if we distribute over the surface several galvanoscopic frogs, they are seen to be agitated only on the points, to which the nerves that are irritated, abut. More than this, if a nervous filament is irritated towards the extremity of the organ, there is never any discharge in the points of the organ turned towards the brain, which shows that the nervous force that excites the discharge is propagated in the direction alone of the ramification of the nerve, as in muscular contraction, and that consequently it is at the extremity of the nervous filaments that the cause acts which produces the manifestation of electricity.

These points being established, if we bear in mind that the irritation of the nerve places it in a state of electric polarity, we shall understand that the diaphragm in which it ramifies must itself assume a peculiar electric state. Now, it is that one of the two surfaces of the diaphragm, upon which the nervous ramifications abut, which is negative, whilst the other is positive. In order to explain this differ-

ence, it seems to us necessary to assume that the two species of nervous fibres, that abut upon the organ, are polarised in contrary directions, the one so that the positive poles of their particles are turned on the side of the organ, the other so that their positive poles are turned on the side of the nervous centre. The former would be those which penetrate more deeply into the diaphragm; whence it would follow that they polarise its molecules in the same direction as they are themselves polarised, which would constitute a positive state for the upper surface of the diaphragm. The latter would be those which, as we have seen, are simply adherent in the lower surface of the diaphragm by means of expansion similar to nucleoles, and do not penetrate into it, which is a cause that they must communicate simply to this surface their negative state. We have thus all the conditions united for constituting a voltaic pile, namely, a succession of solid diaphragms, all parallel in a horizontal plane, positive on one of their surfaces and negative on the other, then a conducting electrolytic liquid interposed between these diaphragms. Furthermore, these diaphragms are 2,000 in number in each of the piles; and there are in all, in the torpedo, 940 similar piles. This simple enumeration is sufficient to explain the electric power of the apparatus without its being necessary to suppose for each nervous filament an electric state more powerful than that which we have found for them in ordinary animals; only here, by the effect of the peculiar arrangement that results from the organisation of the electrical apparatus, the individual actions of these nervous filaments are all added instead of remaining isolated, as is the case when the filaments are ramified in the ordinary muscles.

We are obliged, it is true, to admit that the nerves which abut upon each diaphragm of the organ have two different polarities; but this supposition appears to us valid, first, from the fact that the nerves in question are not identical, since some terminate in a manner entirely different from the manner, in which the others terminate. Moreover, how are we to explain, without this hypothesis, the mode according to which the reunion of the two electricities is brought

about? Indeed, when muscular contraction is in question, we have admitted that electric equilibrium is re-established between the positive extremity of the nerve, which abuts upon the muscle, and its negative extremity, which is in communication with the nervous centre, by means of currents that circulate in the different parts of the body. But here, the action of the nerves that set out from the fourth lobe of the brain is altogether special and local; and it is necessary that the electric equilibrium should be established in a circuit, of which the fourth lobe, the nerves that proceed from it, and the organ into which they ramify, alone form part. Now, the electric excitation setting out from the nervous centre, nothing is more natural than to assume that the polarisation which results from it is propagated according to a certain direction in one part of the nervous fibres, and according to the other direction, which in substance is only a continuation of the former, in another part of these fibres; in like manner as, when rubbing or heating a body under certain conditions, it is so polarised as to have at one of its extremities free positive electricity, and at the other negative. We may further remark, that the double part played by the nerves that abut upon the electric organ would be similar to that of the nerves of motion and sensation, which we have seen must, when they are excited, be polarised in contrary directions.

Let us add, in order to anticipate every objection, that even though the positive and negative electricities do not accumulate, except at the extremities of the prisms of which the organ is composed, it is not necessary, in order to obtain the electric shock, to touch the prism exclusively upon the two surfaces of the organ; it is sufficient, in order to receive the discharge, to be in conducting communication with these two surfaces; and the skin of the animal, always in a moist state, is itself able to fulfil this office. It is true that the discharge is then less powerful, seeing that we collect only a more or less considerable derived portion of it, the greater part being necessarily brought about by the intervention of the exterior surface of the fish.

It follows, therefore, from the foregoing theory, that we make the electric function of the torpedo to depend upon the same nervous force, that produces muscular contraction, that is to say, upon a modification in the electric state of the nerves, arising from an action of the brain, which itself depends upon the will, or which may be excited either in the brain itself, or more directly still upon the nerve, by any artificial irritation whatever.

The gymnotus and the other electric fishes owe their properties to causes similar to those, which we have just analysed in the torpedo; they have all, in fact, like the torpedo, a particular organ, which is the electric organ; and although among them this organ differs in its general arrangement and in its structure in certain points from that of the torpedo, it is easy to see that its organisation is analogous, and that the part it plays is identical.

The gymnotus, or Surinam eel *, the most studied of these fishes after the torpedo, differs totally from it by its exterior aspect; it is long, flexible, greenish-grey, similar to a long serpent, presenting a rather large head, with eyes placed above; it attains to a length of eight or ten feet. The electric shocks that it puts forth are much more powerful, and especially more sustained than those of the torpedo; we know, by the very picturesque description that Humboldt has given of the fishing for gymnoti, that their electric discharges are able to numb horses and mules, which are compelled to remain in the water in which many of these fishes are found congregated, so as to cause them to fall into this water, in which they are drowned. But the strength of the gymnotus is soon exhausted, and it requires rest and an abundant feeding in order to be again able to possess a great electric power. The gymnotus lives in river water, and not, like the torpedo, in salt water; it is necessary, when it is captive, frequently to change the mass of water in which it lives. All these observations, and others besides, concur in showing that its electric func-

* There are two species of gymnotus, the *gymnotus electricus* and the *gymnotus royal*, but they differ in only a few unessential points.

tion is always, as in the torpedo, proportional to the activity of respiration and nutrition, as well as to the degree of rest of the muscles of the animal.

Faraday has succeeded in determining the direction of the electric current in the gymnotus, which he found to be from the head to the tail in the wire of the galvanometer, one of the extremities of which communicates with the head, the other with the tail, so that the positive electricity is accumulated at the anterior part of the animal, and the negative electricity at its posterior part. The electric discharge of the gymnotus is, therefore, directed from its head to its tail in the water in which it is plunged; also, when it is curved, the part of the water comprised in its curvature is traversed by a group of electric filaments dispersed about, which kill the small fish that are in their route by giving them shocks. Faraday has also obtained, with the electricity of the gymnotus, the decomposition of iodide of potassium, the magnetisation of steel needles, and the induction spark. Schœnbein, who had the opportunity of repeating the greater part of Faraday's observations upon the same gymnotus, that had been employed in the experiments of the English philosopher, succeeded in producing bright sparks, and even the combustion of gold, by causing two gold leaves to communicate respectively with the head and the tail of the electric fish. He caused the discharge to pass through a chain of many persons, all of whom felt a very violent shock.

Finally, MM. Miranda and Paci made a detailed study of the electric properties of the gymnotus upon one of these fishes, that arrived from Rio Janeiro at Naples in 1844; and upon which M. Matteucci and I were enabled to make several experiments together in 1845, at the period of the meeting of the Scientific Congress. It appears to me to be well established, by multiplied observations, that the electric shock depends only on the will of the animal; but, with regard to the opinion put forth by the two Neapolitan philosophers, that the gymnotus directs its current whither it wishes, and proportions its intensity to the resistance that it undergoes, it is only an illusion. The gymnotus is only able, by the flexibility of its body, to curve itself so that the

animal which it desires to kill may be on the right line, that passes through its head and its tail, and consequently on the direction of the current which, otherwise, disseminating itself in the liquid, traverses all the bodies that it encounters; it is in this sense only that it may be said that the gymnotus directs its current. With regard to the supposition that the gymnotus proportions the intensity of its current to the resistance that it undergoes, the facts upon which it is founded are explained very naturally by calling to mind that the effect of the current is always more sensible in the points in which the resistance is the greatest. And if, when the gymnotus is touched by an insulating or insulated body, it gives only very feeble and scarcely sensible discharges, as if it knew that the discharge could not traverse the body, this effect is due, as M. Matteucci has remarked, to the fact that the fish, suffering a more powerful sensation by the portion of the discharge, which in this case is obliged to pass through its body, it is led, by this sensation, no longer to continue its discharges.

MM. Miranda and Paci have produced all the magnetic, calorific, and chemical effects, that had already been obtained before this, with the electricity of the gymnotus; they have, beyond those who went before them, succeeded in decomposing other electrolytes besides iodide of potassium, and in particular nitrate of silver and acetate of lead. M. Matteucci and myself have observed a fact, which well assimilates the current of the gymnotus to that of a voltaic pile; it is, that when the animal is touched, on the one hand, at the middle of its body, and on the other hand at the head or at the tail, a current is obtained in the galvanometer, which is in intensity just the half of that which is developed when the two touched points are the head and the tail themselves.

The gymnotus, in effect, possesses, like the torpedo, an electric organ composed of a great number of prisms similar to piles. But only these piles are directed from the head to the tail of the animal, instead of being transversely, as in the torpedo, from the belly to the back. M. Pacini, who has made an anatomical study of this organ, has found that it is formed of partitions, which are thin and of a fibrous nature,

c (*fig.* 349.), directed from the head to the tail, and which perform the office of walls of the prisms of which the organ is composed. These prisms are separated into a very great number of compartments by diaphragms, A A, which have the form of small, long, and narrow membranes, and which are situated perpendicularly to the length of the animal, so that one of their faces is on the side of the head, and the other on the side of the tail. As in the torpedo, we may call the former *the upper faces*, and the latter *the lower faces*, if we suppose the gymnotus suspended vertically, the head upwards, the tail downwards; a supposition that we have made in *fig.* 349., which represents its organ. The distance of the partitions gives the measure of the width of the diaphragms, which varies from $\frac{1}{25}$th to $\frac{1}{10}$th of an inch; with regard to their length, it is as a mean $\frac{2}{3}$ths of an inch, a quantity which consequently expresses the width of the partitions. The diaphragms follow, parallel to each other in each prismatic canal, from one extremity to the other of the electric organ, at very small distances. M. Pacini has found that the space occupied by ten successive diaphragms was, at a mean, $\frac{1}{30}$th of an inch, which gives a mean distance of $\frac{1}{200}$th of an inch from one diaphragm to the other. He has observed, in an angle of the organ, series of diaphragms so irregular, that he has distinguished them under the name of abnormal diaphragms, B (*fig.* 349.); they are as it were wasted, narrower, and more distant from each other than the normal diaphragms.

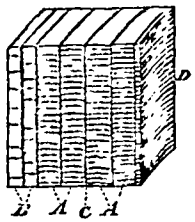

Fig. 349.

In a gymnotus of mean length, namely, about 31 inches, the electric organ is found to be about $25\frac{1}{2}$ inches; it is deduced from this that the number of the electric diaphragms, in a single series, is nearly 4000. According to Hunter, the number of prismatic canals is about 48 on each side*, or 96 in all; these 96 piles each contain 4000 dia-

* These 48 prismatic canals are distributed between two organs, separated by an adipose stratum, one of which, the *great electric organ*, contains 34, and the other, the *small electric organ*, 14.

phragms. In the torpedo there are 940 piles, or series of diaphragms, in place of 96; it is true that each of the piles contains only 2000 diaphragms instead of 4000. It follows however, from this comparison, that the number of the diaphragms is much more considerable in the torpedo than in the gymnotus. But, on the other hand, their surface is much greater in the gymnotus than in the torpedo, since it is 0·075 square inches in the former, and only 0·0105 square inches in the latter. Another difference is, that the space occupied by two successive diaphragms is considerably greater in the gymnotus than in the torpedo; since, although they include only a double number of diaphragms, the prisms are about 15 times longer.

This greater thickness of the cells is connected with a complication of structure, which M. Pacini has observed; in fact, each diaphragm of the gymnotus is composed of two solid parts, superposed, but separated from each other; one of a cellular appearance, the other very thin, formed of *fibriles*. There are, moreover, two liquids, one interposed between the *cellular* body and the *fibrilline* plate, and the other between two successive diaphragms. The cellular body, that forms the upper part of each diaphragm, is principally formed of a thick undulating plate, semi-transparent, which has a mean thickness of about 0·003 inches. From the two surfaces, the upper and the lower of the cellular body, arise a multitude of protuberances, which are, as it were, so many compound cells, intended to increase the surface of the cellular body, especially in its upper part, where they are more elevated, and which by this is rendered about five or six times greater. The free extremity of these cellular protuberances is very near to the fibrilline plate of the diaphragm situated above, but without ever touching it. This space is filled by a liquid which M. Pacini calls *supper-cellular;* the lower cells, fewer and smaller, arrive so as just to touch the fibrilline plate placed below, and which belongs to the same diaphragm; this space is likewise filled with a liquid called *infra-cellular*. With regard to the fibrilline plate, it is composed of a multitude of tendonous

fibriles, which form a species of net of a thickness of about 0·0003 in., and which is fixed upon the edges of the fibrous partitions, not by a simple adhesion as the cellular body, but by continuity of the tissues, for the fibrilline plate is of the same fibrous nature as the partitions. With regard to the nerves, after having traversed the thickness of the partitions, they penetrate into the fibrilline plate of each diaphragm, and they are distributed therein, bifurcating at long intervals; but the quantity of nervous fibres is much less in the gymnotus than in the torpedo, upon an equal extent of an electric diaphragm.

To sum up, we see that to each electric diaphragm of the gymnotus correspond four parts, which succeed each other from above downward, the gymnotus being always supposed placed vertically, the head upward,—the super-cellular liquid, the cellular body, the infra-cellular liquid, and the fibrilline plate; this plate, which constitutes the lower part of the diaphragms, represents their negative surface, which shows that, in the gymnotus as in the torpedo, it is the face of the diaphragm in which the nerves are distributed that is the negative face.

M. Pacini thinks he sees in the electric apparatus of the gymnotus an image of the two-liquid pile, in which the fibrilline membrane would play the part of the porous partition. The chemical action would take place between the infra-cellular liquid and the cellular body, the super-cellular liquid filling only the office of conductor. In order to explain the influence of the will of the animal on the production of electricity, M. Pacini assumes that the chemical reactions being in great part subordinate in the animal economy to the nervous action, it is this action which brings about the chemical effect, whence the electric effect results. Thus, whilst in the torpedo the production of electricity would be an immediate effect of nervous action, this production in the gymnotus would be only an indirect effect of this same action, which, by exciting a chemical action, would thus bring about the manifestation of electric signs. M. Pacini bases his opinion upon the fact that, in the electric

organ of the torpedo, the nerves predominate, and the materials are in less quantity, whilst in that of the gymnotus it is the materials that predominate, and the nerves that are in defect.

In whatever manner the nervous force acts in the gymnotus, it is no less indispensable in the gymnotus than in the torpedo for the production of electricity; we know, in short, from the observations of M. de Humboldt, that the discharges of the gymnotus entirely cease when the brain has been removed, and that we do not succeed in obtaining them even when the spinal marrow is irritated. This fact is the more significant, since a great part of the nerves that ramify into the organ of the gymnotus come from the spinal marrow. But, on the other hand, we are ignorant whether there exists in the brain of the gymnotus, as in that of the torpedo, a particular lobe, whence the electric influence would emanate. Moreover, whatever may be the differences of structure between the electric organ of the torpedo and that of the gymnotus, it appears to me difficult to admit that there are in the nervous influence two modes of action so different, according as we refer to one or other of the two electric fishes. I am rather disposed to assume that in the gymnotus, as in the torpedo, the primitive source of the electricity is in the nerves; but recognising that the chemical reactions which this electricity excites in the two organs sustain this electricity, and contribute to the formation of the electric circuit. Might not the difference of structure of the two organs be connected with the difference of conformation of the two fishes, one of which, long and flexible, the other wide and rigid, could not evidently contain similar electric apparatus? The surface being proportionately greater, and the number of the electric diaphragms being smaller in the gymnotus, comparatively with the torpedo;—might not this arise from the difference of the two media in which they are called to live, the less conducting fresh water for the former, the more conducting salt water for the latter? The fact is, that when it is once well demonstrated to us, by the researches of M. Dubois-

Reymond, that the nerves are endowed with an electricity proper, and that it is by electrical means that the nervous influences are transmitted, it appears to us eminently probable that the thing which characterises electric fishes is the presence in them of a special organ which, by its structure, by the manner in which the nerves are distributed in it, accumulates, while preserving to them their nature, the electric effects of such of the nerves as are directed into it,—effects which, for the other nerves in these fishes, and in other animals in which there are no similar organs, are transformed into contractions, secretions, &c. But we recognise that, in order to confirm our manner of viewing it, it would still be necessary to make numerous and important researches, both upon the torpedo, and upon the gymnotus especially.

There exists one other fish, the *silurus electricus*, the electric organ of which has been the subject of a detailed examination on the part of M. Pacini, who has found that it is formed (*fig.* 350.) by small membranes, B B, which intersect in different directions, and constitute the sides of spaces or cells of octahedral forms of about 0·00006 cubic inches in capacity, and filled with an albuminous liquid. This singular electric organ forms beneath the skin, A A, a spongy layer, that envelops the whole body of the animal, minus the extremity of the snout and the different fins, so that the fish is enclosed in its electric organ as in a sack. It is to be remarked that its body is not found in immediate contact with the *electric sack* that encloses it, but that there exists a thick adipose layer, E E, interposed, which seems intended for insulating the body of the animal, and for preserving to it its electricity proper; a layer separated in like manner by a strong fibrous membrane of octahedral cells.* This precaution appears the

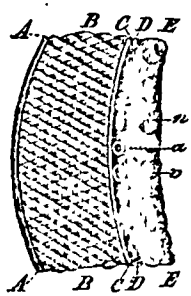

Fig. 350.

* It is into the fibrous membrane that the nerve penetrates at *n*, the artery at *a*, and the vein at *v*.

more necessary, since in the silurus, the diaphragms of the organ not being arranged in parallel series, but all in many different directions, the electric discharges may be directed in a host of various directions, and consequently may come out from all the points of the surface of its body; so that, without the insulating adipose layers, the silurus would be exposed to suffer from the electric effects, to which it gives rise itself. It is to be presumed that the electric organ is to it rather an arm of *defence*, as are the spikes of the hedgehog; whilst it is an arm of *offence* in the torpedo and the gymnotus.

Production of Electricity in Vegetables.

On seeing the vital force in animals bring about electric phenomena, it has been often asked if, under the empire of this same force, there would not be manifested in the act of vegetation some signs of electricity. Many attempts have been made with this in view; and if the results of them are still uncertain, it is due to the difficulty of isolating the various causes, which may give rise to electric manifestations, when we are operating upon living vegetables. Among these causes, the most active are undoubtedly the chemical reactions either of the moist parts of the vegetables upon the solid or liquid conductors intended for drawing off their electricity, or of the different fluid portions of the vegetables upon each other. The differences of temperature of the various parts of the same vegetable may also have some influence. Finally, the action of atmospheric electricity, of which living vegetables are excellent conductors, must also sometimes be felt in the perception of vegetable electricity.

Without going back to ancient observations, the vague and uncertain results of which cannot inspire any confidence, we shall confine ourselves to referring to the researches of MM. Pouillet, Becquerel, and Wartmann. M. Pouillet, on causing plants to germinate in insulated capsules and in the midst of an atmosphere sufficiently dry, succeeded in collecting negative electricity in the capsules, which indicated that an equal quantity of positive electricity had passed into the

air. M. Riess, on repeating these experiments, did not obtain so much constancy in the manifestation of electric signs as M. Pouillet had found in them. MM. Becquerel and Wartmann operated in another manner. Their process consisted in inserting in different parts of a vegetable points or plates of platinum, placed in communication with the extremities of a galvanometer. The results obtained by these two philosophers are almost similar. They have both found electric currents in all parts of the plant, and in all seasons of the year. In the same transverse section of ligneous plants, the current is directed from the sap towards the fresh bark passing through the point of contact. The bark and the sap are negative relatively to the heart of the tree. The parts of the bark that contain the juices (the *parenchyma*) are negative relatively to those which are situated higher. The descending juices in the sap (the *cambium*) are negative in regard to those which are in the leaves. If one of the points of the galvanometer is plunged into the ground near the roots of a plant, and the other in contact with the leaves, or inserted in the bark, a current is manifested, which indicates that the earth is charged with an excess of positive electricity, and the bark and leaves with negative electricity. Very little or no effect is obtained when one of the needles is in the wood near the pith, and the other in the ground. Vegetables, whatever they may be, even those which have an herbaceous stem, present the same effects. Becquerel concludes from this that in the act of vegetation, when germination is accomplished, the ascending sap, which communicates with the ground by the intervention of the roots, constantly transmits to it the excess of positive electricity, of which it obtains possession in its reaction upon the liquid, that is found in the cortical parenchyma, whilst this liquid acquires the contrary electricity, which it furnishes to the air by evaporation. Vegetation would act in a direction inverse to the causes which make the air to be in general positive, and the earth negative; and, in certain cases, there might result from this an influence over the electric phenomena of the atmosphere.

Becquerel believes that closed currents constantly circulate in the interior of each plant, which are directed from the bark to the pith, and thence to the extreme branches; and he attributes the production of these currents to the presence of two different liquids, reacting chemically upon each other by the intervention of tissues that are very little permeable. He remarks that these two liquids, which are the ascending sap and the parenchymous sap, are in the desired conditions for liberating currents without the intervention of metal plates, namely, for forming contacts by insensible transitions. M. Wartmann also admits the existence in the interior of plants of closed currents, of which the currents collected are only derivations. He also agrees with M. Becquerel upon the point that the layers of the bark are negative in respect to the ground. This latter philosopher, by thrusting platinum needles fixed to the extremities of the galvanometer into different parts of the tuber of the potato, found currents which demonstrated to him the heterogeneity of the juices that are found in the tissues from the epidermis to the centre, — an heterogeneity that appears to be in relation with the organic constitution of the tuber. The action of water upon these various juices in like manner brings about currents in which the water acquires positive electricity; so that M. Becquerel arrives at the conclusion, from his numerous observations, that the electric effects in question are so complex that great care must be taken in drawing conclusions from them as to the part that electricity must play in the organic functions, and consequently in the phenomena of vegetable life.

M. Becquerel's doubts are found to be confirmed by the very complete researches that M. Buff has recently made upon this subject. In order to change as little as possible the natural conditions in which a plant is found to be placed, M. Buff has employed water as the medium for establishing communication between divers points of the plant and the galvanometer. The experimental arrangement was the following: — Two glass vessels contained a layer of mercury of about 0·78 in. in thickness, into which were plunged the extremities of two platinum wires, enclosed in glass tubes.

Upon the mercury water was poured; the platinum wires were made to communicate with a galvanometer, and, on closing the circuit with a band of moist paper, he satisfied himself of the absence of all electro-motive force due to the heterogeneity of the mercury; there scarcely ever existed any electro-motive force of this kind, or, if one existed, it was made promptly to disappear by the agitation of the mercury; the difficulties were thus avoided which would be presented if the platinum wires had been in direct contact with the water. Then the band of paper was suppressed, and the two parts of the plant, whose electric state it was his desire to examine, were made to plunge under the water.

M. Buff first compared the electric state of the leaves with that of the roots. The plant having been removed from the ground, and its roots well washed in a current of water so as to remove all the adhering earth, without in any manner altering the state of the surface, the roots were made to plunge into one of the vessels, and the leaves into the other. A current is thus obtained constantly directed from the roots towards the leaves through the plant, but the intensity of which varied from one plant to another. In order to be quite sure of the absence of all foreign electro-motive action, the plant was reversed upon itself, and the direction of the current was immediately changed. When operating upon very dry or very resinous, and consequently very slightly conducting plants, several individuals were arranged parallel to each other in the same experiments. In this manner the plants, of which the following is the list, were examined: —

Apple tree.*	Beta oleracia.	Raspberry.
Plum tree.*	Daucus carota.	Tobacco plant.
Fir.*	Oxalis stricta.	Various cereals.
Rose tree.*	Mignonette.	Cactus opuntia.
Various Euphorbia.	Tricolour violet.	Erica Urceolaris.
Common roundsel.	Dog-tooth violet.	Acropera Laddigesii.†

Branches separated from the vegetable were then ex-

* The experiments were made with very young shrubs.
† Plants of the family of orchids.

amined, by plunging the leaves into one of the vessels full of water, and the cut extremity into the other. A current was always obtained directed through the plant from the artificial section laid bare towards the leaves. Experiments were made in this way upon the preceding plants and upon a certain number of others, of which the following is the list:—

Oak.	Tea.	Tropæolum majus.
Hornbeam.	Spiræa ulmaria.	Various fungi.
Willow.	Vine.	Horseradish.
White poplar.	Pinus silvestris.	Oak.
Paulownia imperialis.	Pinus canceolata.	Poppy.
Maple.	Sedum tectorum.	Juniper.
Nerium oleander.	Sedum hybridum.	Gooseberry.

The currents thus obtained have frequently remained for several hours without ever changing direction.

If the bark were removed in any point of the plant, and if the part thus laid bare were made to plunge into one of the vessels, the leaves plunging into the other vessel, a current was always obtained directed in the interior of the plant from the part laid bare towards the leaves. Between two intact leaves no current was established; but if one of the leaves was torn, a current was produced directed from the torn leaf towards the leaf remaining intact.

A current might even be obtained with a single leaf, by making a tear in it, and establishing a circuit between the tear and the intact portion of the leaf. These experiments prove clearly that the currents in question do not exist in the living plant, since we can give to them any direction that we desire in respect to the organs of vegetation, by suitably choosing the point at which the interior of the vegetable is laid bare.

The young and fresh bark, the buds, and the flowers, behave exactly like the leaves. It is the same with a certain number of fruits: such are grapes, apples, plums, barberries, the berries of privet, the capsules of horseradish, the pods of vetches, &c.

It is not necessary to remove all the bark in order to ob-

serve the effects that have just been described; it is sufficient to tear the epidermis. The interior of the bark, therefore, behaves in respect to the leaves like the interior of the wood.

Finally, even in mushrooms, similar phenomena may be observed; the interior of the mushroom is negative in respect to the intact surface. The experiment was made upon the following mushrooms:—

Agaricus campestris.	Agaricus muscarius.
Agaricus nodus.	Lycoperdon gemmatum.

We may therefore regard it as established that *the roots and all the external parts of plants, which are filled with the juices of vegetation, are negative in relation to the surface, more or less moist, of the leaves, the flowers, the fruits, and the young branches.*

The reason of this phenomenon is easy of conception. The interior of the plant contains juices of various natures, which cannot pass through the epidermis, whilst the exterior moisture always soaks a little into this membrane. We have then in contact a membrane soaked with water, and vegetable organs charged with liquids of various natures; if we establish between this membrane and these organs a closed circuit, a current must evidently be produced. But it also appears evident that this current has a relation only very indirect and very remote in respect to the phenomena of vegetation.

It therefore appears to us demonstrated, that hitherto we have no proof of the existence in living vegetables of an electric state analogous to that which we have found in the muscles and nerves of animals; and that all the traces of electricity that have been collected may be attributed simply to ordinary chemical reactions, and in some cases, as we shall see, to atmospheric electricity. The phenomena of the osmotic force lately studied by Graham are not contrary to this conclusion; since it is to a chemical action that he attributes the production of the electricity that, according to him, accompanies endosmose.

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Humboldt.—Animal Electricity. *Ann. de Chim.* t. xxii. p. 51.—Gymnoti Electrici. *Ann. de Chim. et de Phys.* t. xi. p. 408.

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Matteucci.—Animal Electricity. *Arch. de l'Electricité*, t. ii. p. 419. and 626.; t. iii. p. 5. and 153. *Ann. de Chim. et de Phys.* t. lvi. p. 439.; and t. lxviii. p. 93. *Ann. de Chim. et de Phys.* (*New Series*), t. vi. p. 30.; t. viii. p. 309; t. xv. p. 64.; t. xviii. p. 109.; t. xxiii. p. 230. *Philosophical Transactions of the Royal Society of London* (1847—1850).—Electric Fishes. *Bibl. Univ.* t. xi. (1837), p. 392.; t. xii. p. 163. and t. xvii. (1838), p. 37. *Arch. de l'Electricité*, t. i. p. 571. and t. v. p. 491. *Ann. de Chim. et de Phys.* (*New Series*), t. xxi. p. 160.—Muscular Respiration. *Comptes rendu de l'Acad. des Sciences*, t. xlii. p. 648.; and *Arch. des Sc. Phys.* t. xxxii.; *Traité des Phenomènes Electro-physiologiques des Animaux*, Paris, 1844.

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E. Wartmann.—Vegetable electricity. *Arch. des Sc. Phys.* t. xv. p. 301.

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CHAP. II.

ATMOSPHERIC ELECTRICITY.

The Existence of Atmospheric Electricity, and the Means of proving it.

THE ancients, although in point of fact very ignorant of the physical sciences, had nevertheless studied with some care atmospheric phenomena. The Etruscans, who devoted themselves to it in a very special manner, had sought in it the means of predicting the future, of turning aside baneful presages, and of appeasing the gods. They had especially observed all that related to flashes of lightning, of which they recognised three sorts, according to the gravity of their effects; they even distinguished eleven species of lightning, according to the theory which they had deduced from their observations. The Romans admitted but two,—those of the day attributed to Jupiter, those of the night attributed to *Summanus*. According to the Etruscans there were lightnings that came out of the earth (*infera, terrena*), others which came from the sky (*à sideribus venientia*); the latter always struck obliquely, whilst the former rose perpendicularly. The most mysterious part of the science of the Etruscan aruspices assuredly consisted in the ceremonies by which they pretended to draw down lightning; it was the worship of *Jupiter Elicius*. The Etruscans had brought it to Rome; Numa had learned from them the secret of it, and he had recorded the detail of these rites in his commentaries; his successor, Tullus Hostilius, having desired to repeat these redoubtable ceremonies, but not having taken the necessary precautions, was killed by lightning.

The belief in the *fulgural science* lasted a great number of centuries; and Constantine the Great, having become a

Christian, had still faith in it, since, several years after his conversion to Christianity, he made a law for authorising the Romans to consult the aruspices when an edifice had been struck by lightning. Later still, and in the time of the siege of Rome by Alaric, some Etruscans presented themselves to the prefect of that city, and assured him that they had been witnesses of the defence of a city by means of certain ceremonies which had drawn down lightnings and whirlwinds of fire, and had thus delivered it from its enemies. They offered to defend Rome in this manner, and the priest whom they consulted authorised a trial, which, however, produced no result.

Some authors have thought that the recitals and superstitions of the Etruscans concealed some true physical knowledge; they thought they found traces of them among some other people of antiquity, and have cited the opinion of Michaelis, who has maintained that the gilded points which were found, according to the historian Josephus, upon the top of the Temple of Jerusalem, performed the office of lightning conductors, and protected this edifice from lightning. They alleged also a passage from Ctesias, who speaks of two swords, the iron of which possessed the virtue of dissipating clouds, hail, and whirlwinds. But these indications, added to all we know of the *fulgural* theories of the Etruscans, could not prove the existence of a veritable science. We can merely conclude from them that certain electric phenomena had been remarked in antiquity. Thus, those small flames had been observed which appear on the summits of ships' masts, and which sailors at the present time call *St. Elmo's fire*. The lights had been seen which sometimes shine at the points of spears and swords; and the Romans had already remarked them eight years after the expulsion of the kings, during the war against the Sabines. But all these phenomena were never referred to their real cause; for it is evident that the Etruscans had no true knowledge of electricity; they were only objects of superstition, taken advantage of by the priests of Jupiter Elicius.

We must come to the middle of the eighteenth century,

to Franklin, in order to obtain the proof that the phenomena of lightning, of thunder, and of the effects of lightning, are due to electricity. However, before the illustrious American, the identity, that exists between these electric phenomena, had been greatly suspected. After having produced for the first time the electric spark, Doctor Wall immediately compared it to claps of thunder. The analogy was striking; and philosophers endeavoured to establish it by approximations more or less ingenious. But all passed away in reasoning, from which nothing could be concluded, because in physics it is experiment alone that must decide. Franklin therefore entertained the bold thought of going to seek for electricity in the very bosom of the clouds; as the question was only to convey a body into the region of thunder, he conceived the idea of employing the kite; and, after some fruitless attempts, he succeeded in drawing from the extremity of the string which held the kite, that was thrust into the midst of the clouds, a bright spark, which was followed by several others. Franklin's experiment took place in 1752; it was made at the same time in Europe with success by several philosophers, and among others by Dolibard at Marly, and by M. de Romas. This latter, in June, 1753, having conceived the happy idea of placing a wire in the whole length of the twine by which the kite was retained, obtained energetic effects; he had been able to draw off sparks of nine or ten feet in length, and an inch in thickness, which were accompanied by a stunning noise. Notwithstanding all the precautions, that he had taken to insulate his apparatus by means of glass rollers, M. Romas was once knocked down by the violence of the blow, but his fall was attended by no fatal result; whilst Richmann, at St. Petersburg, was struck by the electricity of the clouds, which he had drawn into his study by means of a conductor. It was then proved, in an evident manner, that lightning is only an electric discharge. We shall see further on the conditions and forms that are proper for this mode of the manifestation of electricity, as well as the means of preserving oneself from its attacks; we must first study more closely, and apart from

the accidental phenomena to which it gives rise, the electric state of the atmosphere.

Lemonnier was the first who, by means of insulated metal rods, had proved that even in a serene state the air is charged with electricity. Beccaria confirmed these results, extending them, and endeavouring to determine the various circumstances that influence the electricity of the atmosphere when there is no storm. But the two philosophers who devoted themselves to this subject with the greatest care, at the end of the last century, are, unquestionably, De Saussure and Volta. Instead of fixed apparatus, such as insulated points placed at great heights, and put into communication by wires with the observer, these two philosophers employed portable electroscopes, furnished at their summit with an iron rod capable of being elongated, and which was raised in the air to a greater or less height by holding the instrument in the hand.

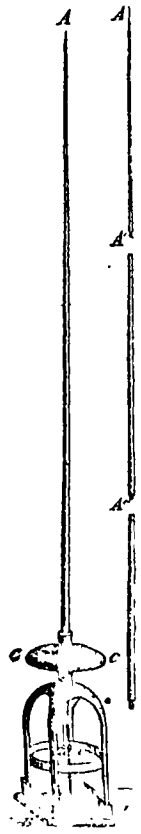

Fig. 351.

De Saussure's electrometer, which is still employed with advantage on account of its facility of transport, is formed of two fine wires (*fig.* 351.), each terminated by a small pith ball, *a a*, and fitted to a metal rod, fixed at the upper part of a bell-glass, B B. The two small pendulums are thus placed in the interior of the bell. The rod is itself surmounted by a conductor, A, terminated in a point, composed of three parts capable of being adjusted into each other, and each about eight inches in length; this conductor is intended to collect the electricity above the head of the observer. In order to preserve the electrometer from rain or snow, a small brass cap, C C, of a conical form, and four inches in diameter, is screwed to the upper part of the bell. A divided scale is applied to one of the faces of the glass cage, in order to appreciate the angles of divergence of the two pendulums.

De Saussure graduated his apparatus as follows: — Having taken two electrometers as equal and similar as possible, he electrised one of them so that the two pith balls receded, for example, 0·23 in.; with the hook of the other electrometer, which was not electrised, he touched the hook of the former; the electricity was instantly distributed between the two, and the divergence was, in one as in the other, 0·15 in. Having removed the electricity from one of the electrometers, he placed it anew in contact with the other, and the recession was 0·11 in. The three divergences of 0·23, 0·15, 0·11 in. corresponded, therefore, with intensities, as 1, $\frac{1}{2}$, and $\frac{1}{4}$. De Saussure thus succeeded in forming a Table which, in point of fact, changes from one apparatus to another, but which every observer is able to establish before commencing a regular series of observations.

Volta substituted, for the wires furnished with two small pith balls, two blades of straw about two inches in length, suspended to two small and very mobile rings, fitted to the stem of the electrometer, and which, in the state of rest, are contiguous. These small straws, when they are dry, are much lighter than the wires, and present more surface. When the apparatus is sensitive, its march is regular up to 26° of recession. Volta recommends to place at the extremity of the point of the stem that surmounts his electrometer a lighted body, intended for drawing off electricity at greater distances; he obtained effects often double of those which were indicated by the apparatus without the presence of the lighted body.

However, of all electroscopes, the most sensitive is that with gold leaves, which we have described in the First Volume of this Treatise; it is very well adapted to observations of atmospheric electricity, as has been done by Mr. Ronalds at Kew, by perfecting it in certain points, and in particular in the insulation of its several parts.

As we have seen above, there are two very different modes of making these observations: the one consists in having very elevated insulated rods, intended for drawing off the electricity of the air, and bringing it down by conducting

wires into the electrometric apparatus; the other depends upon the employment of portable instruments, which are placed in different regions of the air. In the former mode, we may obtain a true current of electricity, if we make the end of the wire that communicates with the insulated point abut upon one of the ends of a galvanometer, the other end of which is in communication with the ground; a deviation of the needle is obtained, the amplitude of which depends upon the quantity of the electricity, and upon the facility with which it escapes. M. Colladon, who was the first to succeed in collecting atmospheric electricity in this manner, took care to insulate the convolutions of the wire of the galvanometer well, as he had moreover done in the construction of the galvanometer intended for the electricity of machines.* But this apparatus is not very sensitive, seeing that it requires, in order that the magnetised needle may deviate a few degrees, a considerable quantity of electricity and a very great conductibility of the air and the ground in order that the escape may be continuous, which does not always take place.

The second mode of observation, which consists in having portable instruments, is founded upon the principle that the charge of the instrument arises from the induction exercised upon it from a distance by the electricity that the air, in the midst of which it is placed, possesses at the moment of the experiment. In this respect there is no advantage in terminating the conductor, with which the electroscope is surmounted by a point; a ball is preferable, for it permits the instrument better to retain the electricity that it has acquired. The only difference is that, when the instrument is terminated by a point, the electricity of the contrary name to that, with which the acting part of the atmosphere is charged, escapes by this point; whilst with the ball it is the electricity of the same name that escapes by the hand or by the conductor, which must be placed in communication with the electrometer whilst it is under experiment. In this latter

* Vol. I. p. 328.

case, the apparatus indicates an electricity of the contrary name to that which has charged it. It is upon this latter principle that Peltier has constructed one of the best atmospheric electrometers that exist, and the employment of which has been very useful in the study of this electricity.

The following is the description of this apparatus (*fig.* 352.): —

A copper rod, A B, terminated at its upper part by a hollow ball of the same metal, C, four inches in diameter, and at its lower part by a much smaller ball, B, is fixed by the intervention of this latter to a copper stem, which descends into a glass cage, from which it is insulated by means of a plug of gum-lac. This stem bifurcates, forming a sort of ring, D D, at the centre of which is found a point *m*, intended to receive a very mobile needle, *a b*. The needle *a b* is constantly retained in the magnetic meridian by the aid of a much smaller magnetised needle, *c d*, forming a system with it, and attached above the cap. Independently of this needle, another needle, E F, also of copper, but stronger, is solidly fixed to the stem, which descends into a glass tube filled with gum-lac, and let into a wooden tablet; all the metallic part is thus found to be insulated, so that the loss of electricity must be very feeble. The instrument is placed upon a stand with three feet or screws, by means of which it is placed horizontal. The ball B, in turning around the tube A B, causes the part G of the central stem to ascend or to descend; when we desire to make use of the apparatus, this part G is raised; the system of the two needles *c d* and *a b* is then able to move freely upon the point of the stem *m*.

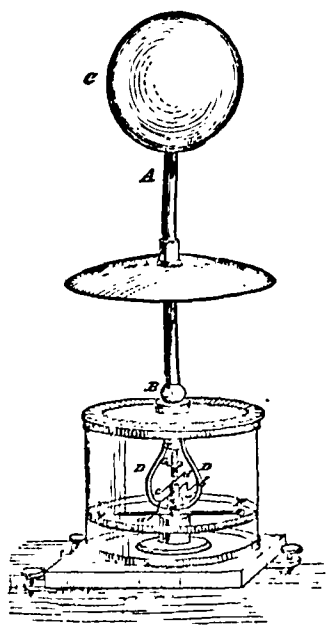

Fig. 352.

When the instrument is to be placed at rest, G is lowered, and the motion of the needles is found to be restricted.

When we desire to operate, the instrument is set so that the fixed needle, E F, is placed in the magnetic meridian; the mobile needle *a b*, which moves with the magnetised needle, places itself parallel with the former. Suppose the ball C is situated below a body positively or negatively electrised, there is an action by induction; in the former case, the negative electricity, arising from the decomposition of the natural electricity, is disguised at the upper part of the ball, and the positive electricity is driven back into the lower part of the instrument, and causes the mobile needle *a b* to deviate a certain number of degrees, measured by means of two divided circles, one of which is cemented upon the tablet, and the other upon the upper disc of the glass cage, in order to avoid the errors of parallax.

This apparatus, under this hypothesis, detects the action of induction exercised by the electrised body charged positively; but the needle may be charged negatively by touching the knob with the finger, and removing the electrised body. In operating with a negatively electrised body placed at a distance, the apparatus is charged by induction with positive electricity.

The employment of Peltier's electrometer rests upon an important fact, observed by Ermann. This philosopher had placed, at a certain height in the atmosphere, a gold leaf electroscope, without having been able to collect electricity. In a higher stratum of air he carried a wire placed horizontally at the extremity of an insulating rod, and then lowered it rapidly until it touched the electroscope; the apparatus immediately indicated positive electricity in the region in which the conductor was situated. The effect was inverse when this latter was situated in a lower stratum, and was rapidly raised. This fact is easily explained. The atmosphere is charged with positive electricity, which increases in intensity in proportion as we rise, as will be seen further on; the earth, on the contrary, conducts itself as if it were charged with negative electricity. If, therefore, we

suppose that a body, in electric equilibrium with a given space, is raised or lowered, that is to say, approaches a space charged with a greater quantity of positive electricity, or recedes from it, it must present an excess of negative or positive tension, arising from an action by induction; on returning rapidly into its former position, the body will recover the natural state. It is an effect of this kind that had caused some philosophers, especially M. Pálagi, to think that there is a liberation of electricity by the mere fact that one of two conducting bodies is brought near to, or is withdrawn from the other: the analysis of these curious effects has demonstrated that they arise from an inductive action, exercised by the electricity with which the air is naturally charged. MM. Gay-Lussac and Biot, in their aërostatic voyage, had already observed an effect analogous to that which has been described by Ermann.

Peltier, dwelling upon this action by induction, proposed to operate as follows:—He ascends a terrace arranged for this purpose, placing the instrument upon an upper slab raised between four and five feet; it is reduced to equilibrium by touching the stem in the lowest part; he re-descends and places the instrument upon the lower slab, which is intended for it. In reducing the instrument to equilibrium, the arm must be raised as little as possible; for if it be raised sufficiently high to touch the globe, the hand, becoming negative by induction, would repel the negative electricity from the ball; it would neutralise the positive portion that it should attract to it, and the instrument would become negatively charged at the moment when the hand should be withdrawn. It is therefore necessary to touch the stem as low down as possible, and even with a fine body, as a wire, in order to avoid the induction of the mass of the hand upon the rest of the stem. Being reduced to equilibrium during its elevation, the instrument on being lowered gives signs of negative electricity, whilst on being raised it gives signs of positive. In operating it is necessary to have regard to this inversion, so as not to be led into error as to the true sign of atmospheric electricity. We shall note, therefore, a positive

tension, when the electrometer shall give a negative sign in descending, and a negative, if the instrument, when brought down, marks a positive sign.

It is not sufficient to know the angles of deviation of the needle; it is further necessary to determine the forces that are proportional to them. Peltier produced this determination by the torsion balance. M. Quetelet employs De Saussure's more simple and sufficiently accurate method, which has been already explained, and which requires the employment of two instruments perfectly similar.

Study of the Electricity of the Atmosphere in the Normal State.

After having described the principal facts which have set philosophers in the way of recognising the existence of an atmospheric electricity, and the most efficacious means of collecting this electricity, we must now endeavour to acquaint ourselves with the electric state of the atmosphere. Under this head we must distinguish the normal electric state, such as it exists during serene weather, and the exceptional state, that constitutes stormy weather. We shall see that, without the weather's being precisely stormy, the presence in a serene atmosphere of a fine cloud, of the fall of rain or snow, is sufficient to modify the normal electric state; but the modifications that bring about these aqueous precipitations are far from possessing the importance that results from the existence of a true storm, accompanied by thunder and lightning. We shall occupy ourselves in this paragraph with the determination of the normal electric state of the atmosphere, and with the modifications that are introduced into this state by the causes that we have pointed out, reserving for the following paragraphs that which concerns storms and the exceptional electric phenomena that accompany them.

The air under a perfectly serene sky is constantly positive, but this positive electricity is not uniformly distributed in the atmosphere; it is, it is true, at very nearly the same

intensity in a horizontal strata, but stronger in the upper strata, and stronger still as we rise higher. This had been already recognised by De Saussure and Ermann. At the surface of the ground the electricity is null; it does not commence to be sensible in the open country until about a yard or a yard and a half above the ground. When there are, on the surface of the ground, trees, buildings, in a word elevated bodies, the height at which the air begins to give signs of positive electricity becomes greater. It evidently seems that the air and the earth are charged with contrary electricities, which re-combine continually in the lower strata of the atmosphere, either directly or by the intervention of bodies placed upon the surface of the ground. We conceive, therefore, that the height at which the positive tension of the air becomes sensible must vary with the facility with which this neutralisation is brought about, which itself depends upon many circumstances, in particular upon the degree of humidity of the air. M. Becquerel has proved the increase of positive electricity with the height by shooting with a bow arrows, to which was fixed one end of a silk thread covered with tinsel, the other end of which communicated with an electroscope. The experiment was made at the great St. Bernard, and upon one of the plateaux which are in the vicinity of the hospice. Peltier recognised the same fact by means of a captive balloon; only he remarked that, under certain circumstances, when clouds that are scarcely visible exist in the air, the electricity became null, then negative, to become positive again shortly after.

M. Quetelet, in operating with the electrometer, and according to Peltier's method, found, at the end of a great number of observations, that in a place in no degree dominated by neighbouring bodies the electric intensity of the air increases, setting out from a given point, proportionately to the heights; but he was able to verify this law only within very confined limits. His object was especially to inform himself what was the constant height at which it was necessary to place oneself in order properly to make regular

observations on atmospheric electricity. He had established at the top of the tower of his observatory a little platform, surrounded by an iron balustrade, from which came out an apparatus that enabled him to raise the electrometer several yards in height, and to reduce it to equilibrium in each of its positions; it was necessary that the slab upon which the instrument was placed should dominate over all the neighbouring bodies, and especially the balustrade. In fact, the point where the electricity was null was situated at very nearly the height of the balustrade.

It follows, from all that precedes, that it is important, in order to make good observations of atmospheric electricity, that the conductor, whatever it may be, that indicates the electric state of the air, by itself participating in this state, must be placed at a sufficient height in order to dominate over all surrounding bodies. Thus, when this body is the extremity of an insulated metal point, it is necessary that it be situated at the top of a very elevated mast, as at the Observatory of Paris, where this mast was placed upon the roof of the building; or, as at that of Geneva, where the mast fixed in the earth was of sufficient length for the platinum point, by which it was terminated, to be about eighty-six feet above the ground. When the body that receives the electricity is the conductor, which itself forms part of the electrometer, as in the experiments made at Brussels by M. Quetelet, and at Munich by M. Lamont, it is necessary to take care in each observation to elevate the instrument to a height such that it is not dominated.

The first tolerably regular observations of atmospheric electricity are due to De Saussure, who had studied its diurnal variations, and had found a first maximum between 8 and 9 A. M., a first minimum at 6 P. M., a second maximum at 10 P. M., and a second minimum at 6 A. M. But he did not regard these determinations as being very precise; he had, indeed, remarked that they change with the season: those which we have been pointing out refer to the summer months, and differ notably from those which relate to the winter months. Lemonnier and Beccaria had already re-

88126

marked these variations in the electric state of the air with the hours of the day.

Schubler in 1811 had concluded, from several observations, that the first minimum in each season takes place at very near sunrise, and the second minimum between 2 and 5 P. M. in all the months equally; that the hour of the first maximum varies with the seasons, being for the months of June, July, and August from 6 to 7·30 A. M.; for the months of September, October, and November from 8 to 9; for December, January, and February from 9 to 10; and for March, April, and May from 7 to 8·30. The hour of the second maximum, which takes place between 7 and 10 P. M., also varies with the seasons.

Arago, as the result of regular observations made in 1830 for some time at the Observatory of Paris, had found the hour of 8·48 A. M. for the first maximum in the month of March; M. Plantamour at Geneva had arrived at the same result, namely, that he had obtained a first maximum between the hours of 8 and 9 A. M.; then a minimum, such that there was scarcely any electric sign, between noon and 3 P. M.; finally a second maximum, but less powerful than the former, between 8 and 9 P. M.

The number of philosophers that have been engaged in observations relative to atmospheric electricity is very considerable; unfortunately there are but few among them who have pursued them for a long space of time. Clarke in Ireland, Romershausen and Dellmann in Germany, Palmieri in Naples, have all found a diurnal variation in atmospheric electricity collected with a serene sky; only they differ in a slight degree as to the precise hour of maxima and minima, and M. Palmieri at Naples does not find the diurnal period so decided as it appears to be in more northern localities.

M. Peltier, without having given himself up to very consecutive observations on atmospheric electricity, has, however, had occasion from time to time to make very precise observations upon it on the days in which the atmosphere was perfectly serene and pure. He found that after a first minimum, which takes place at about one hour before sun-

rise, a first maximum arrives, which varies from 6 to 11 A. M., according to the season; then a minimum presents itself a little before sunset, and it is followed by a second maximum towards 9 or 10 P. M. The intensity, setting out from this hour, diminishes until it attains the first minimum of the following day. The signs of electricity, which are always positive, weaken throughout a day more in proportion as the evaporation is more considerable. Thus, M. Peltier has sometimes observed in the same day 150° to 200° at the morning maximum, and 3° or 4° at the afternoon minimum; but it happens very frequently that variations so great are followed by storms.

The observations which, on account of the very long time (several years) during which they have been continued, as also by the precision and care with which they have been directed, appear to us calculated to inspire the greatest confidence, are those of Mr. Ronalds at Kew, collected and discussed by Mr. Birt, those of M. Quetelet at Brussels, and those of M. Lamont at Munich.

The Kew observations have been made by means of ordinary electroscopes placed in communication with an insulated conducting apparatus elevated above the ground, and intended to collect in the best possible manner the electricity of the surrounding air. These observations have been to the number of 15,170 for a period of five years; of this number 14,515 are of positive electricity, and 655 of negative. The observations of positive electricity have furnished the elements of the determination of the ordinates of diurnal and annual curves of atmospheric electricity, principally during the three years 1845, 1846, and 1847, to which 10,176 observations have contributed. The following has been the result of the discussion relative to the diurnal curve.

From the mean of the three years, at each of the hours of observation, namely at all the even hours, Greenwich mean time, during the day and the night, it appears that the tension of atmospheric electricity is at its minimum at 2 A. M. Setting out from this hour, there is a gradual increase until

6 A. M.; after this hour the tension increases more rapidly, its value at 8 A. M. being almost double that of 6 A. M.; the increase is then more gradual until 10 A. M., the period of the first, or morning maximum. Setting out from this hour the tension declines gradually until 4 P. M., a period at which its value is only slightly superior to that of 8 A. M. This second minimum is called by the author *diurnal* minimum, in order to distinguish it from the *nocturnal* minimum, which takes place at two in the morning. After that the tension increases rapidly until 8 P.M.; and after a slight rise at 10 P.M., the period of the principal or evening maximum, the ascending march of the tension is terminated. The evening maximum is notably superior to that of the morning, or of 10 o'clock. Between 10 in the evening and midnight, the tension decreases almost to the value of the diurnal minimum.

With regard to the annual period, we may remark that the lowest tensions are manifested in June and August, that of July being slightly *superior* to that of the two months named above. In September there is a feeble elevation, which increases in October. This increase becomes more rapid from November to January; it then suffers a period of arrest, the increase in February being less than those of December and January. In February, the maximum is attained, to which succeeds in March a rapid diminution in tension, which follows on in April and May, the diminution attaining its minimum in June, the month in which the tension is at its lowest point.

The observations at Brussels were made by M. Quetelet, with Peltier's electrometer, according to the method that we have pointed out in the preceding paragraph. We shall here insert two tables, selected among all those that M. Quetelet has published, and which appear to us to present a very exact idea of the results obtained. The first is relative to the monthly variations of the electricity of the air; the second gives the electricity of the air in its relations to the state of the sky.

MONTHLY VARIATIONS FOR THE ELECTRICITY OF THE AIR.

Months.	1844.	1845.	1846.	1847.	1848.	Mean.
January -	„	471°	562°	957°	487°	605°
February -	„	548	256	413	295	378
March -	„	262	95	282	164	200
April - -	„	93	94	221	155	141
May - -	„	163	49	67	59	84
June - -	„	51	39	47	48	47
July - -	„	58	33	43	61	49
August -	90°	89	57	11	64	62
September -	91	95	62	39	63	70
October -	110	299	98	107	120	131
November -	127	334	274	160	152	209
December -	340	742	799	356	281	507
Annual Mean	„	267	202	225	162	206

ELECTRICITY OF THE AIR IN ITS RELATIONS WITH THE STATE OF THE SKY.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Clouded sky	268°	220°	129°	17°	46°	36°	41°	56°	42°	75	109°	181°
Serene sky	1133	493	261	149	63	37	35	64	78	168	226	571

The observations, made with the view of proving the annual variations of the electricity of the air, were made each day about noon, and commenced in August, 1844. The results of each year perfectly accord, and may be summed up in the following manner: — 1st. Atmospheric electricity, considered in a general manner, attains its maximum in January, then decreases progressively until the month of June, which presents a minimum of intensity; it increases during the following months to the end of the year. 2nd. The maximum and the minimum of the year have, for their respective values, 605° and 47°, so that the electricity in

January is thirteen times as energetic as in the month of June. The mean value of the year is represented by the values that are given of the months of March and of November. 3rd. The absolute maxima and minima of each month follow a march absolutely analogous to that of the monthly means: the means of these extreme terms equally produce the annual variation, although in a less decided manner. In order to determine the intensity of the electricity of the air in its relations with the state of the sky, M. Quetelet has separated, for each month of the year, the numbers that referred to an entirely clouded sky, from those observed during a serene sky, or rather a sky presenting so few clouds that eight or nine tenths at least were entirely unclouded. In order not to complicate the results by foreign influences, he omitted the observations made during storms, snows, rains, and fogs. The Table thus formed has made manifest the following results: —

1st. Whatever the state of the sky may be, the electricity of the air presents a maximum in January, and a minimum toward the summer solstice.

2nd. The difference between the maximum and minimum is much more sensible during serene weather than during cloudy weather. Under the latter circumstance these numbers are 268° and 36°, the ratio of which is about 7. In serene weather the maximum of January is 1133°, and the minimum of July 35°; the ratio of these numbers is 32, a considerable value.

3rd. During the different months, the electricity of the air is more powerful when the sky is serene than when it is cloudy, except toward the months of June and July, when the electricity attains a maximum, the value of which is nearly the same, whatever be the state of the sky.

Setting out from this epoch, the electricity of the air, during a serene sky, exceeds the electricity observed during a clouded sky, so much the more in proportion as we approach nearer to January; and in this latter month the

ratio is more than four to one. This powerful electric intensity during a serene sky, in winter, is a very remarkable circumstance, and had been already proved by all philosophers who had been engaged with atmospheric electricity, although they attributed to it a much less relative value.

M. Quetelet has collected into a special Table the observations made during extraordinary circumstances, such as fogs, snows, or rains, and which he had not employed in the calculation of the means. The following are the results that he has obtained. The electric intensity observed during fogs has, at a mean, almost exactly the same value as that observed during snows. This value is very high, and corresponds to the mean maxima observed for the former and the latter months of the year. It does not seem, moreover, that it is subject to the influence of seasons. The values observed during a tranquil rain differ very little from the ordinary values that are observed during the course of the year. Under certain circumstances a powerful electricity, either positive or negative, has been observed at the approach of rain or after rain. During the four years that are embraced by M. Quetelet's observations, the electricity has been observed negatively only twenty-three times at the ordinary hours of these observations; and he remarks that it has been observed negatively only once during the four months of October, November, December, and January. These negative electricities generally preceded or followed rains and storms; the following is the manner in which they are distributed: the electricity has been observed negatively six times during rain, nine times before rain, five times after rain, twice during rains that fell at remote distances, once without apparent cause.

From the collection of observations, made in order to prove the diurnal variation of the electricity of the air, M. Quetelet deduces the following conclusions: —

1st. The electricity of the air, estimated at a height always the same, suffers a diurnal variation, which generally presents two maxima and two minima.

2nd. The maxima and minima are displaced according to the different epochs of the year.

3rd. The first maximum happens, in summer, before 8 A.M., and about 10 A.M. in winter; the second maximum is observed after 9 P.M. in summer, and about 6 P.M. in winter. The space of time that separates the two maxima is therefore more than thirteen hours at the epoch of the winter solstice.

4th. The day minimum presents itself about 3 P.M. in summer, and toward 1 P.M. in winter. Observations have been insufficient to establish the march of the night minimum.

5th. The instant that best presents the mean electric state of the day in the different seasons occurs about 11 A.M.

We shall not dwell upon M. Lamont's observations at Munich; although they are made with Peltier's electrometer, and after the same method as those at Brussels, they differ from them very notably as to the results. We shall be able to judge of them from the subjoined Table, in which M. Quetelet has united the observations of Brussels, of Kew, and of Munich, made at the hour of noon, and which he has rendered comparable by taking the monthly mean as a unit.

Months.	Numbers Observed.			Proportional Numbers.			Brussels.	
	Brussels.	Kew.	Munich.	Brussels.	Kew.	Munich.	Proportional Numbers.	Observed Numbers.
January	518°	182·4°	6·34°	2·82°	2·40°	1·48°	1·61°	50°
February	333	179·3	5·98	1·81	2 35	1·39	1·45	45
March	169	58·2	5·18	0·92	0·76	1·21	1·13	35
April	105	40·7	3·04	0·57	0·54	0·71	0 77	24
May	81	41·3	2·56	0·44	0·55	0·60	0·65	20
June	40	26·8	3·11	0·22	0·35	0·72	0·55	17
July	42	31·8	3·15	0·23	0·42	0·73	0·55	17
August	62	28·5	3 03	0·34	0·38	0·71	0·68	21
September	74	31·0	2·83	0·40	0·41	0·66	0·81	25
October	140	65·1	3·59	0·76	0·85	0·83	1·03	32
November	230	80·5	5·51 *	1·25	1·34	1·28	1·29	40
December	412	126·3	7·20 *	2·24	1·65	1·68	1·48	46
The year	184	74·3	4·29	12·00	12·00	12·00	12·00	31

* These numbers belong to 1850; the preceding to 1851.

It follows from these observations that the electric tensions, in winter and in summer, are as 9 to 1 for Brussels, as 6 to 1 for Kew, and as 2 to 1 only for Munich.

M. Quetelet attributes the remarkable differences between his observations and those of M. Lamont essentially to the method employed by this latter philosopher for deducing from the direct indications, furnished by the instrument, the real electric state of the air. This method, founded upon calculation, differs from the experimental method employed both by Peltier and by M. Quetelet himself for graduating the electrometer, and which consists, as we have seen, either in estimating the value of the degrees of the instrument by referring the electric changes to the balance, or by drawing out a Table, according to De Saussure's method, founded upon the distribution of electricity between balls of equal surface.

Whatever may be its cause, so great a divergence between the results obtained by observers so distinguished as MM. Lamont and Quetelet, points out to us how much uncertainty there still is in the very precise determination of atmospheric electricity. This uncertainty is not due to the imperfection of the instruments alone, but also to the nature of the phenomenon, which is eminently complex. The question is, in fact, to estimate the variations in the electric state of the stratum of air, the influence of which may cause itself to be felt upon the instrument employed. Now, are the strata of air in identical conditions in all places of observation? The configuration of the ground, the buildings or trees which cover its surface, which are never similar,—are they not able to influence, in a different manner according to the localities, the electricity of the neighbouring strata of air? The extent of the stratum that acts upon the electrometer must itself vary with the sensitiveness of the instrument, and it is not certain that the changes which the electricity of the air undergoes follow the same laws in a limited stratum and in a very extended stratum. Thus M. Lamont's electrometer, which is surmounted by a much less considerable ball than

that of M. Quetelet must be of a much less sensitiveness, and may consequently give different results.

But, of all circumstances, that which most surely influences the indications of the instrument is, without any doubt, the humidity of the air. It is true that Peltier's electrometer escapes in part the action of this cause, because it is only influenced by the induction of the atmosphere, or rather, by the difference of the inductive actions of the earth and of the atmosphere by which it is enveloped; but if, instead of being terminated by a ball, its stem is terminated by a point, by a bundle of points, or by a lighted wick, as in the experiments of De Saussure and of Volta, there is brought about, besides the phenomena of induction, a radiation of electricity into space, which is much influenced by the humidity of the air, by rain, and by the force of the wind,—causes which do not in a sensible manner affect the instrument when it is surmounted by the ball. But it is especially when operating with fixed apparatus that the action of the moist surrounding air causes itself to be felt by diminishing the insulation of the point or the ball intended for collecting the electricity of the stratum, in which it is placed. In vain is the insulating stem of a glass that is but little hygrometric; it is impossible to avoid, during very moist weather, its becoming covered with an aqueous film, which, however thin it may be, is nevertheless conducteous. In order well to appreciate the general influence of the moisture of the atmosphere upon the variations of atmospheric electricity, it is therefore necessary to operate with Peltier's electrometer surmounted by the ball, which, of all apparatus, is the one that is most sheltered from the accidental disturbances that we have pointed out. This is what M. Quetelet did; and the results consigned to the following Table, and which are the summaries of the observations made by this learned observer at Brussels, from 1842 to 1847, must in this respect inspire the greatest confidence.

Months.	Electricity, Mean of.		Mean of the Maxima and Minima.	Hygrometer, during the Electrical Observations.		Hygrometer in general, 1842 to 1847.	Electricity during Moisture.		Electricity in general.
	Maxima.	Minima.		Maxima.	Minima.		Maxima.	Minima.	
January -	71·9	27·8	49·8	92·6	94·8	93·7	53·0	55·0	50
February -	64·5	26·9	45·7	87·5	88·4	92·2	45·2	44·3	45
March - -	55·5	18·6	37·0	84·7	85·1	90·3	36·2	26·0	35
April - -	41·4	9·2	25·3	83·3	84·1	89·3	21·7	20·6	24
May - -	37·0	4·3	20·6	80·2	80·3	87·6	15·0	19·0	20
June - -	31·9	2·9	17·4	83·8	80·5	84·6	27·0	11·0	17
July - -	33·0	3·3	18·1	75·1	77·1	88·1	23·0	6·0	17
August - -	54·2	7·8	21·0	83·4	78·9	88·7	9·0	5·0	21
September -	35·5	16·0	25·7	84·8	83·9	91·8	17·5	12·5	25
October -	50·5	10·3	30·4	87·2	91·2	94·4	27·7	44·0	32
November -	56·3	20·0	38·1	91·3	94·7	95·0	28·0	47·0	40
December -	69·7	30·5	50·1	92·7	92·7	95·7	50·0	53·7	46
The year -	48·45	14·80	31·62	85·55	85·97	99·0	29·44	28·62	13

A very remarkable fact, which arises out of this Table is, that moisture acts in a manner altogether different in the cold months and in the hot ones; it increases the electricity in the winter months, it diminishes it in the summer months. The fundamental fact is, that humidity acts in two manners, the effects of which tend to oppose each other. On the one hand, it facilitates the escape of the electricity accumulated in the upper regions of the atmosphere to the stratum in which the observation is made; on the other hand it facilitates the escape into the ground of the electricity which this stratum possesses: thus, on the one hand, it increases the intensity of the electric manifestations of the instrument, on the other hand it diminishes them. This diminution has been proved by Peltier, who has observed in particular that the more moist the air is, the more is it necessary to elevate the electrometer (three or four and even thirty-two feet), in order to obtain the same sign of electricity that is easily obtained on raising it only seven or eight inches when the sky is serene.

It would be necessary, in order to explain this double action, to know better than we do know the influence of the vapour of water, of temperature, and of the elastic force, upon electric conductibility. But, whatever it may be, there is

no doubt that the hygrometric state of the air influences in a very decided manner the electric manifestations. Is it simply as facilitating the transmission of electricity? is it perhaps also, as a reservoir itself of electricity, that moisture acts in the manifestations of atmospheric electricity? This is what we shall endeavour to analyze in the following paragraphs, in which we shall be occupied with the electricity of fogs, and of clouds, and with the origin itself of atmospheric electricity. We shall confine ourselves for the present to pointing out the effect without endeavouring to discover its cause.

Although the conducting power of the air, when it is moist, is much more considerable than when it is dry, M. Quetelet was never able, when employing the galvanometer (even a very sensitive* galvanometer) for collecting atmospheric electricity, to obtain effects sufficiently decided for recognizing either a diurnal or an annual action. The manifestations of atmospheric electricity in a dynamic state, such as are furnished by the galvanometer, do not take place in a very sensible manner, except at the approach of storm clouds, and during fogs, rains, and snows. With regard to the direction of the currents that are obtained in these cases, it frequently changes, as we shall see when engaged upon storms.

Notwithstanding all the imperfections and the divergences that are still presented, by the various observations relative to atmospheric electricity, they nevertheless agree on certain important points. They all lead us to recognize that, setting out from the ground, in which there is no electric manifestation, in proportion as we rise in the atmosphere, when it is serene and in the normal state, we find constant signs of positive electricity, which go on increasing. They indicate moreover, for a same height in the atmosphere, a variation in the electric state of the air, both monthly as well

* He employed a Gourjon's galvanometer of 2400 convolutions, very sensitive, communicating at one of its extremities with a metal rod elevated above the roof of the Observatory of Brussels, and terminated by a tuft of very fine platinum wires, and at the other extremity with the ground exterior to the building; the rod and the galvanometer were insulated with the greatest care.

as diurnal. The monthly variations are such that the maxima of electricity, indicated by the instruments, happen in the months in which the days are shortest; and the minima, in those in which they are longest. The diurnal variations differ notably in amplitude with the places of observation; they are very generally in relation with the variations of the humidity of the air; in this sense, that the hygrometric state and the electric state of the air would seem to follow a tolerably parallel march. However, philosophers are not completely agreed as to this complete parallelism, at least during all the months of the year equally.

The anomalies and divergences are probably due to the fact, that the influence exercised by the presence of aqueous vapour upon the electricity detected by the instruments placed in a stratum of air, altogether changes in nature, when this vapour, in precipitating, becomes visible under the form of cloud, fog, or rain. It even happens, as would seem to follow from the sudden changes observed in the electric state of the air, that precipitation often begins to take place, even before being visible; this is, moreover, proved by the fact, that rain has sometimes been seen to fall in weather completely clear, and in the absence of all cloud. Under the influence of these aqueous precipitations, which disturb the normal state of the atmosphere, not only does the positive electricity no longer follow its regular march in the intensity of its signs, but it is frequently seen to change into negative electricity of greater or less force. The manifestations of negative electricity, made by the instruments intended for collecting atmospheric electricity, generally precede, accompany, or follow the appearance of storms, or even that of simple clouds, as well as the fall of rain; it is not to be said that they are presented in all cases in which clouds, storms, and rain are manifested; they require much cloud, &c., but they only take place under these circumstances. Thus we postpone what we have to say upon it to the following paragraph, which is devoted to the abnormal electric state of the atmosphere. It is in this same paragraph, also, that we shall point out the irregular and

sudden variations of intensity that are manifested by the positive electricity, a phenomenon which, like the preceding, indicates a disturbance in the electric state of the atmosphere.

But, before terminating the present section, we must necessarily touch upon a question which we can only glance at for the present, seeing that we shall have to return to it in the section relative to the origin of atmospheric electricity. This question is,—to know what conclusion we must draw from the indications of atmospheric electrometers on the real electric state of the air and of the terrestrial globe. According to M. Peltier, the terrestrial globe is completely negative, and interplanetary space positive; the atmosphere itself has no electricity, and is only in a passive state, so that the effects observed are due to the relative influence of these two great magazines of electricity. With regard to ourselves, without discussing for the present this opinion, we are disposed to assume that the terrestrial globe possesses, at least on its solid part, an excess of negative electricity, and that it is the same with bodies placed at its surface; but it appears to us to follow, from the various observations that we have detailed, that the atmosphere itself is positively electrised; this positive electricity evidently arises from the same source as the negative of the globe. It is probable that it is essentially in the aqueous vapours with which the atmosphere is always more or less filled that it resides, rather than in the particles of the air itself; but it does not the less exist in the atmosphere. This is the most natural manner, according to us, of interpreting the results that we have been describing; and we shall see that it finds a confirmation in the phenomena of which it remains for us to speak.

Of Storms and of the Electric Phenomena that accompany them.

We have just seen that, when the sky is not serene, the normal electric state of the atmosphere suffers notable disturbances: the formation of a cloud or of a fog is always

accompanied with a change of distribution in the electricity of the stratum of air in which this formation takes place. It is probable that the positive electricities, with which each particle of vapour is charged, are united in the globule, formed by the re-union of several of these particles, at the moment when their precipitation takes place. The globules are themselves, as we know, so many small spherical balloons, in which a small pellicle of water serves as an envelope to the interior air; now, it is this stratum of water that possesses all the positive electricity which was distributed among the multitude of particles of vapour, which have served towards its formation. But when the globules are collected to form a fog or a cloud, we must not believe that it follows that the fog or the cloud is, as it were, a metallic conductor, all of whose electricity is at the surface; the globules, according to M. Peltier's very just remark, preserve their insulation and consequently their individual electricity; and the fog or cloud must be considered only as an agglomeration of distinct bodies, all possessing their electric charge. The electricity, that envelopes the cloud exteriorly, far from being the total of that with which it is charged, is, therefore, only a very feeble portion of it; and this exterior electric stratum is reproduced after each discharge at the expense of each of the interior globules, which concur in forming the entire cloud. It is easy to prove in several ways that the electricity is indeed thus distributed in a fog or in a cloud; we have only to place an electroscope in the middle of a fog or of a cloud driven by the wind, and we remark how the divergence varies with the passage of the flakes and of the opaque mamillæ; only it is necessary to take care, when a fog is in question, not to place the instrument too near to the earth, because the low portions, too moist and too conducteous, lose their electricity in the ground, to which they are very near.

Another proof that Peltier gives of this mode of the distribution of electricity in a cloud is the fact that a single discharge does not deprive a cloud of the whole of its electricity, which would take place if the latter were all con-

densed at its surface; although there may be only a single clap of thunder in a limited storm, formed of agglomerated clouds, we know that more frequently there are a considerable number of violent and successive discharges. Moreover, it is easy, by suitably arranging an electroscope, when the sky is covered with stormy clouds, so that it may be screened from all lateral influence, to satisfy oneself that the peripheric discharges are preceded by a quantity of special discharges, that take place in the interior of the clouds. We see, indeed, the gold leaves of the instrument diverge suddenly and by shocks, without there being any lightning or thunder. When the leaves have thus diverged by intermittence several times, a clap of thunder is heard, the lightning strikes another cloud or the neighbouring ground; calm then seems to be re-established in the electrometer, but soon the same divergences re-appear, the periphery of the cloud is re-charged with electricity, and a new spark darts forth from it to go and strike the nearest body.

In order to understand well the electric phenomena of clouds, it is therefore necessary to be familiarised with the idea of the individualities of each of the globules of which they are composed. These globules are themselves grouped by small flakes having their limits and their sphere of action like the globules themselves; the small flakes in grouping form larger flakes; the latter form mamillæ; a certain number of mamillæ by their reunion form a cloudlet, and the cloudlets in their turn form definite clouds; the grouping of the definite clouds forms a *cumulus*, and several cumuli a *nimbus*.* Thus these individualities have all peculiar and independent electric spheres, in equilibrium of reaction between themselves, and with the general exterior sphere of the cloud.

* The clouds themselves are distinguished into three species: the *cirrus*, which have the appearance of loose filaments, and which are the highest; the *cumulus*, which are less elevated, have a rounded appearance, and form those large clouds, accumulated at the horizon, which resemble from afar mountains covered with snow; the *stratus*, which are horizontal bands which form at sunset, and disappear at his rising. When the *cumuli* are piled up and become denser, they pass into the state of *cumulo-stratus*, which themselves pass into the state of *nimbus* or rain cloud, which is distinguished by its uniform grey tint and its fringed edges; the clouds of which it is formed can no longer be distinguished, so much are they confounded.

It is only by regarding in this manner the electric state of the clouds, which is in accordance with observation, that we can conceive their enormous power of attraction in certain cases, and the other phenomena which they present.

It is easy now to conceive how rain or snow are found to be charged with an electricity, which they carry onward with them in their fall. Indeed, each drop of rain or each flake of snow must possess the electricity with which the globules of the cloud were charged, which they have served to form by their agglomeration; and this electricity must act by communication or by induction upon the electrometers.

The electric signs, which accompany the fall of rain or snow, like those which are brought about by the vicinity of a cloud, are sometimes positive, sometimes negative. Is this difference in the nature of the electricity detected due to the fact that the clouds really possess a different electric state, or is it only a simple effect of induction at a distance? According to M. Peltier, who in this agrees with the majority of philosophers, there should be positive clouds, and others that are negative; the former should be generally of a rose white or orange; the latter should have a leaden grey or slaty tinge; thus, in a sojourn upon Faulhorn, M. Peltier observed, during six days, a fall of snow and sleet: that of snow, which came from white clouds, being accompanied with a strong positive electricity, that of sleet, which came from grey clouds, with a strong negative electricity. Schubler has found, during the fall of rain, almost as many cases of positive electricity as of negative; and a great number of observers have obtained, by the direct action of clouds upon electrometers, sometimes positive signs, at other times negative. On the other side, M. Quetelet has never observed negative electricity, throughout four years of observations during fogs or snows; he has observed them only during rains, whether they occurred at the point of observation, or were more distant from it; however, of thirty observations of electricity made during rain, there are only six during which the electricity was negative, whilst there are twenty-four during which it was positive. M. Palmieri goes further still;

he considers that there are never any clouds nor consequently any rains intrinsically negative; and that the negative electricity which is observed, and which is frequently very durable when it accompanies the fall of rain, hail, or snow, is an effect of the induction exercised by the strong positive electricity, that is possessed by the cloud and the rain which comes from it. In order to analyse well the series of phenomena, we will suppose a rain commencing to fall at a great distance from the place of observation, which then arrives there under the action of the wind, and which passes onward, without ceasing to fall; the following is the way in which things occur:—

When the rain is very distant, the instruments indicate positive electricity, as they do habitually and almost always with a slight increase of tension.

When the rain has approached within a certain distance, we find a strong negative electricity, which frequently produces powerful sparks to the fixed conductor.

When the rain has reached the place of observation, a great quantity of positive electricity is again found.

When the rain has passed the observatory, we have again a strong negative tension.

Finally, when the rain is sufficiently distant, the atmosphere returns to its habitual positive tension.

Between the respective periods there is a moment of neutrality of short duration.

Thus, then, setting aside the commencement and the end of the phenomenon, in which the atmosphere is simply in its normal state, we distinguish three important periods: 1st, that of the *approach* of the rain, which is negative; 2nd, that of the *vertical fall*, which is positive; 3rd, that of the *departure*, which is negative.

In order to recognise this law, it is necessary that we have an extensive view from the observatory, in order that we may see the fall of rain afar off; for the distance at which the rain commences to produce or to induce negative electricity is very variable. Sometimes, at a distance of thirty miles, this action is already manifested; at other times it com-

mences only when the first drops reach the observer. These differences probably arise from the extent of the shower, and from the electric state of the cloud whence it comes.

Rain, therefore, occupies a region charged with positive electricity, surrounded by a zone charged with negative electricity; so that if the rain commences and ends at the place of observation, positive electricity alone is found; and if it passes to a certain distance without reaching the observer, it is the negative electricity which alone appears. We ought also to note that, in the very frequent case, in which several showers fall simultaneously at some distance from each other, the phenomenon may be much complicated.

We must therefore abandon the idea of negative or neutral rain, and only assume periods separated one from the other by moments of neutrality. Negative clouds do not exist; and negative electricity is observed, during a serene sky, only in the case of a fall of rain, hail, or snow, at some distance. The effects are incomparably more energetic during these three periods; it is then only that the conductors give off strong sparks, and it appears probable that it is under these circumstances only that the phenomenon of thunder and lightning can be produced; so that it should be always accompanied by rain or hail.

M. Quetelet, who for more than ten consecutive years has made regular observations of atmospheric electricity, inclines greatly to the opinion of M. Palmieri; he only believes that this philosopher goes a little too far in absolutely denying the existence of clouds charged with negative electricity. Moreover, he considers that we may sum up what appertains to the effect of a storm cloud, in its more general form, by considering it as follows:—When the air is perfectly pure, the upper strata are electrised positively, in respect to the lower strata; and on considering the surface of the earth as being in the neutral state, the tension of the strata of the atmosphere increases in proportion as we rise. Now, let us suppose a cloud, positively electrised, placed in such an atmosphere, and let us endeavour to account for what happens.

According to observation, everything takes place as if the storm-cloud was surrounded by a negative electric stratum. The thickness of this stratum must not be everywhere the same; for the positive surcharge of the cloud, which determines it, or at least maintains it*, could not be found equally distributed; first, on account of the more or less angular form of the cloud, and then because, in the upper part of the cloud, the surcharge will be driven back in part by the electricity of the upper strata of the atmosphere. This effect will be the more decided as, in following the periphery of the cloud, we shall approximate more to its lower part directed towards the earth. The neighbouring strata of the air, as well as the surface of the earth, will be therefore relatively in a much more decided negative state than if the cloud did not exist; and the difference will be much more sensible than in the top of the cloud.

For an observer placed at a great distance from the storm-cloud, the electrometer raised above the ground gives signs of positive electricity, the indications become more feeble in proportion as the cloud approaches; they are then reduced to zero, and finally the sign of electricity changes. The electrometer indicates negative electricity, not only at the approach of the cloud, but even during the commencement of its passage. However, the electricity diminishes progressively, passes by 0°, and recovers the positive state when the rain begins; it returns to its first value, after having passed through the same phases, when the cloud is sufficiently distant to exert no longer any influence. The sphere of activity of a cloud is everywhere extremely great, and extends to several leagues. It is not a rare thing to see clouds on the horizon indicate their presence by signs of negative electricity.

It is, moreover, evident that the breadth of the negative electric zone, and the intensity of the electricity that is observed in it, like that of the cloud, must depend in great part on the hygrometric state of the air.

Let us dwell more specially on the instant in which the

* M. Quetelet does not pretend to explain the fact; he simply endeavours to conceive more easily its effects.

cloud, surcharged positively, begins to pour forth rain; it will happen that the drops in falling will carry to the earth the electricity of the cloud, and with the greater abundance as the rain shall be more powerful. So long as only a few drops fall, this water only tends in part to paralyse the effects of the negative atmosphere which surrounds the cloud, and which acts upon the electrometer. If we observe the instrument in this instant, we might be disposed to believe that the rain is negative. The change of sign of electricity is, in some sort, gradual. In a shower the change is almost always instantaneous, and the passage through *zero* is, so to speak, not susceptible.

In this state of things, all observers who are situated under the cloud, and in the region in which it rains heavily, would observe positive electricity. On the skirts of the region in which they are placed the electrometer marks *zero;* it then indicates negative electricity, more or less energetic. This negative zone is itself limited by a line, in which the electrometer marks *zero* a second time; and further on it indicates positive electricity, increasing until it is beyond the influence of the storm-cloud.

When the cloud is sufficiently low to touch the surface of the ground, the electrometer indicates the electricity of the cloud itself; the experiment is made in fog, which, as we know, gives a very intense positive electricity. However, the cloud by its contact with the ground must tend rapidly to lose its electric state.

For very elevated positive clouds, giving only a few drops of water, the negative atmosphere that surrounds them cannot extend its action as far as the earth, especially if the electric surcharge is feeble.

When the cloud encounters mountains, it goes towards them the more quickly in proportion as the summits have a more marked negative tension, and it adheres to them, as indifferent conductors, yielding successively its electricity.

This is what is observed in respect to *statical* electricity. Let us now consult the galvanometer, and study the phenomenon, in respect to dynamic electricity. When the cloud approaches, and when it commences to pass, the instrument

generally gives indications of ascending currents; the electricity of the ground is found to be attracted towards the cloud, and sometimes dust is violently raised; but when the rain falls more abundantly, the current becomes descending, the water of the cloud brings down the positive electricity towards the ground; at each clap of thunder, or rather at each flash of lightning, the current passes with more energy, and the needle of the galvanometer is sometimes driven back with force against its stops. It sometimes even happens that the magnetic state of the needle is found to be altered in a durable manner.

Whilst the storm-cloud is moving away, the phenomena manifested by the galvanometer are produced in an inverse order.

Even before the arrival of the storm-cloud, as well as after its passage, the galvanometer gives decided indications at each flash of lightning, and at each electric explosion, which places the cloud in relation with the ground. Sometimes also the direction of the current is inverted.

If the cloud is supposed to be electrised negatively, it would be easy, according to what has just been said, to explain the phenomena that should be produced: let us only remark that, in general, storm-clouds are electrised positively. The clouds that should be exclusively negative would, all things being equal, more escape our observations, and be found in more elevated regions. Those clouds in short placed between the earth, relatively negative, and the upper regions, powerfully positive, ought to tend towards these latter, and their ascent should not stop until there is equilibrium between the electric forces, and the tendency of the clouds to descend.

In all that precedes, we have taken the phenomena in its most simple form, we have considered the action of a single cloud alone; but it will be easy to explain what would happen if several clouds were present, without forming part of a same electric system. Suppose, for example, two clouds positively electrised and superposed; they are found acting by induction, and the lower part of the most elevated cloud will be positively electrised in relation to the upper part of the

lower cloud. This latter, in its turn, will be in the negative state in the upper part, and in the positive state in the part directed towards the earth; the state of the stratum of air interposed between the two clouds will equally suffer their influence, and will depend upon the thickness and upon the hygrometric state of this stratum. On these circumstances also will depend the gradual, or the violent and instantaneous passage of the electricity from one cloud to the other.

If the storm-clouds, instead of being superposed, are situated side by side, and all the same height, they would influence each other laterally; and we should again be able to explain the actions that would arise out of these kinds of induction, in the hypothesis of clouds more or less charged with electricity, more or less positive in relation one to the other. These kinds of actions between storm-clouds render the phenomena ofttimes very complex, and are the cause that many storms may mix and give rise to frequent changes in the electric signs, and in the direction of the currents. We may add, finally, that the nature and the height of the clouds necessarily play a great part in the electric phenomena of the atmosphere.

After having thus studied the electric state of the clouds, let us pass on to storms themselves. Although clouds are all more or less endowed with electricity, certain conditions are necessary, in order that their presence may give rise to a storm. The principal of these conditions, and perhaps the only one, to the production of which the others only concur, is the agglomeration in a same place of as large a quantity as possible of the elementary globules that constitute the cloud, and consequently the presence of a very great number of clouds, and of very dense clouds; it is evident that there results from this a great accumulation of electricity, since each globule carries its electricity with it. This condition is more easily fulfilled in summer than in winter; for in the former of the two seasons, a few degrees of cooling is sufficient to bring about a considerable condensation of vapours. The currents of air, that bring into a same place a great number of clouds, contribute with the former cause to the formation of the storm; although producing a more decided

effect in summer than in winter, it is to them alone, however, that the different storms of winter may be attributed. We may, moreover, divide storms into two classes: the one are due to the action of an ascending current; the other are the result of the conflict of two opposed winds; the former are manifested only during the hot season, the latter during winter and in summer. In our climates, storms are generally formed in summer when the temperature is high, the ground more or less moist, the air calm, and the sky serene; the moist earth, being powerfully heated by the solar rays, there hence results an ascending current of vapours, which become condensed in the elevated parts of the atmosphere; a dense and voluminous cloud may then be produced, which is powerfully electrised. When storms are thus formed, they generally take place at the instant of the most powerful heat of the day; but what is very curious is, that sometimes, in the same locality, the conditions remaining the same, a storm is produced several days in succession, until the wind and atmospheric circumstances have changed. Volta was the first to point out this periodicity, which takes place only for storms, due to ascending currents, and not at all for storms produced by the conflict of two opposed winds.

The presence of clouds in the atmosphere does not always give rise to storms; but storm-clouds have certain distinctive features, by which they are characterised. Among these features, we may mention a sort of fermentation, to which they alone appear to be subject, and which has been observed and described by Beccaria and Forster; to this first feature, we may add, according to Beccaria, the manner in which they are formed and agglomerated. These clouds, generally very dense, rise rapidly from some point of the horizon; they are terminated by a great number of curvilinear and accurately defined outlines; they swell, diminish in number, and increase in size, still remaining invariably attached to their first base. Between them and the horizon is perceived a large, very dark cloud, by the intervention of which they seem to touch the earth, and the obscure tint of which is communicated gradually to the elevated clouds; it is their

general surface, that at least which is perceived from the plain, which becomes more and more black. From the highest parts of this unique and compact mass come out, under the form of long branches, the clouds which, without being detached from it, proceed gradually to cover the whole sky. Independently of these branches, we perceive, here and there in the atmosphere, slight clouds, the movements of which are sudden, uncertain, and irregular, and which Beccaria has called *Ascitizi*, or additional clouds. We may add that the layer of clouds, which seems perfectly smooth on its lower surface, presents on its upper surface high protuberances and deep cavities; this has been remarked by observers who, from the height of very elevated peaks, have found themselves above storms. Storm-clouds, although in general subject to the direction of the winds, seem, however, in certain cases, to abandon that direction in order to follow that of water courses, and in others to be attracted by the summits of mountains.

The height at which storm-clouds may be found has not been determined in a very precise manner; only we may say that it follows from the observations of De Humboldt, M. Saussure, and many others, upon the most elevated summits of the Andes, the Alps, and the Pyrenees, that there are veritable and frequent storms at immense heights above the ocean, at more than 16,400 feet, for example. Can there be, in the countries of the plain, storm-clouds at so great an absolute height? It would seem that we may reply affirmatively, at least from certain isolated observations reported by M. Arago; however, in general, the ordinary heights of storm-clouds are not considerable. There is an example of a storm-cloud, from whence lightning came, which was only 26 feet in thickness, and only 100 feet in elevation above the ground; this was, it is true, an extreme *minimum* case; but in general these heights vary between 650 and 6500 feet. M. Kaemtz is disposed to believe, from a great number of observations made upon high mountains, that storms take place generally at much more considerable heights. The difference of opinion that exists in this respect between

meteorologists may be due to the circumstance, that the region of storms is very extended in the vertical direction, or, in other words, that there is a great distance between the cloud that is nearest to the ground, and that which is most distant from it, among those which concur in the same storm.

When storm-clouds charged with contrary electricity are found reciprocal in their sphere of activity, long sparks commence to dart, even to great distances: this is the commencement of the storm; but soon the attractions and repulsions, arising from their electric state, joined to the action of the winds, which impart to them movements of translation and rotation, bring the clouds near to each other, often giving to them the most fantastic forms; and as soon as they are at a fitting distance from the earth, the noise of the electric discharge makes itself heard.

Before analysing the phenomena of lightning and thunder, let us add that the clouds whose formation we have just described are not the only ones that give rise to the effects of thunder and lightning, but that these same effects are also manifested in the clouds that come out of the craters of volcanoes. Pliny the younger, in describing the famous eruption of Vesuvius of the year 79 of our era, speaks of clouds that opened and allowed long trails of flames, similar to lightning, to escape; and without dwelling upon other observations, we shall confine ourselves to referring to the eruption of 1794, so well described by Hamilton, which was accompanied by stormy clouds that darted forth lightnings, constantly followed by discharges comparable to those of the most violent claps of thunder. This volcanic storm, formed by the simple influence of the volcano, was so similar to ordinary storms that the lightnings which it darted forth produced the customary accidents, and buildings were struck. One cloud in particular was transported by the wind to as far as over the city of Tarento, the distance of which from Vesuvius is 248 miles, and there it struck a house. This cloud was in great part composed of ashes, which were as fine as Spanish snuff. Recent observations of M. Palmieri, to which

we shall return further on, have thrown much light upon the electric phenomena of volcanoes.

We have already pointed out the observation made by Volta of a certain periodicity in storms. It appears that certain local causes, such, for example, as the configuration of the land, the direction of the wind that blows in a valley, may occasion the formation of a storm in preference to another locality. But the causes that bring about storms more frequently embrace a certain extent of country, and then the electric clouds, at first circumscribed, extend in all directions, and come and cover vast surfaces. However, a long series of observations has demonstrated that there exists a certain distribution of storms on the surface of the globe which change with the seasons. A Table, drawn out by M. Arago, shows that the number of storms diminishes from the equator to the poles, as does the quantity of rain. One is even enabled to affirm, from the numerous documents collected by M. Arago, that in the open sea or in islands it never thunders beyond the seventy-fifth degree of north latitude. Although there exists a country (Lower Peru) situated in the equinoxial regions, in which it never thunders, yet it is in these regions, as a mean, that it thunders most. Thus, whilst in France, in England, and in Germany, the mean number of days of thunder rarely rises to twenty, we find that it rises to sixty in Calcutta, and to fifty-three at Rio Janeiro. M. Boussingault thinks that in the equatorial zone all days of the year, probably at all hours, a continuity of electric discharges takes place in the air; and he assumes that an observer, placed at the equator, if he were endowed with organs sufficiently sensible, would constantly hear the noise of thunder. In our climate storms take place in general only in the hot season. The following is a Table, drawn out by M. Kaemtz, of the distribution of storms in the different parts of Europe, according to the seasons; in representing by 1000 the total number of storms during a certain time, we obtain the following distribution of them among the four seasons: —

	Winter.	Spring.	Summer.	Autumn.
Western Europe - -	89	177	525	209
Switzerland - -	4	206	690	100
Germany - - -	14	244	660	82
Central Europe - -	0	157	793	50

M. Arago, in reporting a great number of observations, has been led to recognise that it thunders much less in the open sea than in the centre of continents; he even conjectures that beyond a certain distance from all land it never thunders. M. Duperrey is less absolute; while still being led to admit the diminution of storms at sea and the existence of places at certain distances from islands and continents where it never thunders, he found, however, numerous anomalies. Nevertheless, he has established that it thunders but very rarely on the route that leads in a right line from the Cape of Good Hope to the islands of St. Helena and of Ascension, as well as at those islands themselves; but it is not the same in all other parts of the Atlantic Ocean, the Pacific Ocean, and of the Indian Sea. However, it follows from the collection of observations, gathered in all regions of the globe, that the oceanic atmosphere is much less apt to engender storms than that of the continent and of islands.

Besides the general influences that we have just been pointing out, we must not overlook that there exist local circumstances which influence the frequency of storms. Thus, as we have already remarked, it never thunders in Lower Peru, which, nevertheless, corresponds by its geographical position with the regions where it thunders most.* On the other hand, in Jamaica, from the first day of November to the middle of April, the summits of the mountains of Port Royal commence to become covered with clouds between eleven o'clock and noon; at one o'clock these clouds have acquired their maximum density, the rain escapes from them by torrents, lightnings dart from them in all directions, and finally

* It is true that this absence of storm in Lower Peru is accompanied by the absence of clouds properly so called, and by the substitution for them of a singular vapour, opaque, permanent, known in the country under the name of *garrua*.

the thunder causes its rollings to be heard as far as Kingston; about half-past two the sky has recovered all its serenity: this phenomenon is reproduced every day for five consecutive months. Thus Kingston reckons 150 days of thunder per annum, whilst there are not more than fifty at most in the neighbouring islands and in the points of the continent similarly placed; whence it follows that the influence of the mountains of Port Royal upon the production of storms seems manifest. The equinoctial regions furnish some other analogous examples. There exist some also in the temperate regions. Mr. Dillwyn thinks he has remarked that in mining countries there are less storms than in other countries, and notably than in calcareous countries. M. Blavier, an engineer of mines in France, says that it is recognised in the department of Mayenne, near Niort in particular, that the existence of certain masses of granulous or compact diorite (*grünstein*), which contain much iron, repels or dissipates the most threatening storms, a property that M. Blavier attributes to the conducting action of these masses of diorite. On the other hand, M. Vicat has had the opportunity of remarking at Grondone, on the chain of the Apennines between Genoa and Plaisance, the influence upon the formation of storms of a rich mine of iron, that seems to pierce the ground under the form of a peak. It is rare that a single hot day of July or August passes without an electric cloud forming above the territory of Grondone; this cloud insensibly increases, remains during some hours, as it were, suspended over the iron mine, then bursts forth, discharging itself upon the mine itself.

It is to be regretted that this influence of the nature of the ground upon storms has not hitherto been better studied; it would be a great step gained in terrestrial physics to discover an intimate and decided connection between the geological nature of the ground and the number and force of the storms. This connection very probably exists; and we have even been led to perceive that the nature of the soil is not without influence over the superficial extent of showers.

From the details into which we have entered concerning

storms considered in a general way, let us examine more closely the essential elements by which they are characterised, namely, the production of lightning and that of thunder.

The lightning that darts across the space comprised between two clouds has a duration which does not attain to the thousandth part of a second, as Wheatstone has demonstrated by means of the same principle, by which he has succeeded in determining the time of the duration of an electric spark, which he has found to be lower than the millionth of a second.* There is, however, a form of lightning—that in a ball—the duration of which is greater, as we shall see presently. Further, lightnings are distinguished into three classes: zigzag lightnings, or those of the first class; those of the second class, which are wide and diffuse; and finally, those of the third class, which assume the appearance of balls or luminous globes.

Lightnings of the first class present themselves under the form of a trail of thin light, compact, very defined on the edges, moving in zigzag, being able to divide or bifurcate themselves into two, and sometimes, but more rarely, into three branches. These lightnings direct themselves generally towards the earth, although they are sometimes seen to dart from one group of clouds to another.

The lightnings of the second class give forth a light which, instead of being concentrated into sinuous lines almost without apparent breadth, embrace, on the contrary, immense surfaces. It has neither the whiteness nor the vivacity of the light of forked lightnings; frequently its tint is of a very intense red; blue and violet also prevail in it, from time to time. The lightnings of this class sometimes appear to illumi-

* This principle consists in giving a very rapid motion to a disc, upon the white base of which are traced in colours a great number of rays. When this disc is illuminated by a permanent light, or by one which has a certain duration, the rays are confounded by the effect of the duration of the sensation, if at least this disc turns with a sufficient velocity. But if the illuminating light lasts an instant only, the rays appear distinct, and the disc motionless. It is easy to determine the velocity that must be given to the disc in order that this latter effect may cease to be produced; and to deduce from this determination the duration of the light, knowing that a luminous line assumes the appearance of a continuous circular surface, when it revolves with sufficient velocity around one of its extremities to describe the entire circumference in a tenth of a second of time.

nate only the boundaries of the clouds, from which they emanate; sometimes also their bright light embraces the whole superficial extent of the clouds, and, moreover, seems to come out from their interiors; the clouds then seem to open. The lightnings of the second class are by much the most common; during an ordinary storm millions of them appear for one compacted and sinuous lightning of the first class.

The lightnings of the third class differ from those of the former in respect to form, velocity, and duration. They are visible for one, two, and even ten seconds; they are transported from the clouds to the earth with sufficient slowness for the eye to follow them distinctly in their march. The spaces which they embrace are circumscribed, distinct, and defined, and of nearly a spherical form, which causes them to have been called ball lightnings. They are veritable globes of fire, sometimes dividing, and rebounding upon the earth several times; they have movements sometimes slow, at other times rapid, and sometimes bursting they cause a noise to be heard, comparable to the detonation of several pieces of cannon. Although more rare than those of the second class, they are, however, seen from time to time; and M. Arago quotes a great number of cases of them; it is in general under this appearance that lightning presents itself when it enters the interior of a building. It is probable that the meteoric globes of fire, which sometimes traverse the atmosphere without a storm being apparent, belong to this category of lightnings; but they must not be confounded with the luminous traces that accompany the fall of aërolites.

The three different forms that lightning may assume are not very easy of explanation; they very probably depend upon the form of the clouds and their density, and consequently on the degree of accumulation of the electricity with which they are charged. Much the most frequent case is that of lightnings of the second class, in which the discharge appears to be made among all the particles of the cloud with accompaniment of light; this discharge altogether resembles that of an electric battery, in which the electricity

is powerfully condensed; the different portions of the cloud would be, as it were, so many spangled panes, by means of which a powerful dose of electricity would be accumulated; in the zigzag lightning, the particles of cloud being much nearer to each other, the cloud forms nothing more than a compact mass, from which the electric spark comes out, as it comes out from the conductor of a machine, a case in which it has also the form of a zigzag. This form appears to be due to the resistance which the discharge encounters in the strata of air that it traverses; it is probable, indeed, that the very subdivided particles of water play in the air the same conducting part as that which is played by metal particles, copper, for example, with which a varnished plate is powdered over. In this case, indeed, the spark, instead of traversing the air directly, passes from one particle to the other, forming trails of fire; this effect is obtained in a decided manner by covering magic panes with a layer of aventurine. The appearance of zigzag is therefore due to a propagation of electricity, brought about by means of the successive particles of vapour disseminated in the atmosphere, between which the electricity in escaping forms a series of sparks, following a direction more or less sinuous, on account of the greater or less irregularity of position and aggregation of its conducting particles; the manner of explaining the phenomenon has been developed by M. Dumoncel, who has sustained it by several interesting experiments.* The globular form is the most difficult of comprehension; we do not conceive the origin of this species of luminous ball, which travels in the atmosphere, and which all on a sudden bursts and tears itself with a terrible detonation, in some cases darting rays of zigzag lightning in all directions. These globes of fire have frequently been seen, of the size of a child's head and comparable to the appearance of the full moon, to traverse slowly along the ground, or at a little distance above it, until

* M. Dumoncel considers the water disseminated in the air in the state of vesicular vapour, as a secondary conductor, that is to say, one endowed with an inferior conductibility, which, when interposed between two foci of contrary electricity, enables the discharge to be brought about at much greater distances than through ordinary air.

they escape by some issue, such as a chimney, and burst in coming out. Is this particular form only the result of the manner in which the electricity, due to the influence of the cloud, is propagated through the air, or rather does it arise from a mass of moist air condensed and powerfully electrised, forming as it were a species of small round cloud, and itself set in motion? This it is impossible to decide before fresh observations have made known to us, in a more precise manner, the nature of this meteor. Further, we shall return to this subject in the last section, when we shall be occupied with the cause of atmospheric electricity.

To the appearance of lightnings generally succeed, after intervals of time of greater or less length, noises, which, designated under the general name of thunder, present very great varieties among themselves. Sometimes the noise of thunder appears sharp and dry, like that of a simple pistol shot; more generally it is full and very grave. The thunder is not heard until a greater or less length of time, after the lightning has shone. It is more than probable that the noise and the light are simultaneously engendered; but the velocity of sound being infinitely less than that of light, 1080 feet, instead of 200,000 miles per second, it follows that, provided the observer is at some little distance from the cloud in which the light has shone, the noise of the thunder does not reach him until some instants after he has seen the light. The propagation of the light, being to be considered as instantaneous at the distances in question, the observer, who may have determined with a chronometer the number of seconds comprised between the arrival of the lightning and that of the thunder, will easily deduce its distance in feet from the point, where the meteor was manifested; he has merely to multiply this number of seconds by 1080 feet. The rectilinear distance of the cloud is thus obtained; but we may deduce its vertical height, by determining the angular height of the extremity of the nearest lightning from the observer. There would be great interest in obtaining numerous and exact determinations of the intervals of time elapsed between lightning and thunder, especially of the

greatest and the least; of the former, because they would serve to determine the greatest height of storm-clouds; of the latter, because they would enable us to resolve the question whether the detonation, when the discharge is brought about between the earth and a cloud, takes place towards the earth or towards the cloud, or between the two; a question designated under the name of ascending and descending flashes of lightning. With regard to the first point, the greatest distance at which thunder has ever made itself heard appears about 4 leagues of 12,832 feet, which corresponds to from 48 to 49 seconds elapsed between the appearance of the lightning and the noise of the thunder.

But the noise of thunder presents two characteristic circumstances, which are especially worthy of attention; on the one hand, its long duration; on the other, the successive diminutions and augmentations of intensity, which are frequently renewed during the reverberation of one and the same clap; which is designated by the happy expression of the rolling of the thunder. The duration of the rolling of a clap of thunder, observed in the open country, and corresponding to a single flash of lightning, may attain to 45 seconds, and even more; only care must be taken to distinguish the rolling which accompanies a single flash of lightning from that which arises, as happens sometimes, from an uninterrupted succession of lightnings and thunders. This rolling is attributed to the effect of echoes, which would repeat the noise produced by the single explosion of the discharge; but can there be echoes capable of giving rise to rollings so long as those which frequently accompany thunder? and in the open sea, where there exists no object capable of reflecting sound, the rolling of thunder is in like manner heard. It is true that we may assume that the clouds are susceptible of reflecting sound; we have several examples of this; nevertheless the first objection still remains, and it is a difficult matter to explain, simply by the effect of echo, the constant phenomenon of the particular noise of thunder, still admitting that echo may sometimes strengthen and prolong it. Dr. Hooke, who has established a relation

between simple lightnings and compound or multiple lightnings, and the claps of thunder that follow them, assumes that each of the simple lightnings occupies only a point in space, and produces a short and instantaneous noise; the noise which accompanies the others is a prolonged rolling, because the different parts of the long lines which these lightnings occupy, being in general situated at various distances, the sounds, that are produced by them, either successively or at the same instant, must occupy very unequal times, in order to arrive at the ear of the observer; and consequently, even when they may have been generated at the same time, can only arrive thither one after the other.

M. Peltier explains the rolling of thunder almost in the same manner, attributing it to the successive interior discharges which take place among the agglomerated clouds that compose the *nimbus*, when the electric equilibrium that existed among them has been broken by the first discharge which has taken place at the outer boundary; these discharges, multiplied in every direction by the clouds themselves, by their mamillæ, and their flakes, produce, seeing that they are successive, and that they arise from different points, the rolling and the rumbling of the thunder, without there being any intermittence; it is a consequence of the insulation, or of the individuality of each elementary part of a cloud, and of each of the groups formed by these parts, which we have already seen to be assumed by Peltier. However, we believe with Arago that the discharges due to a same flash of lightning are not successive, but rather simultaneous, still assuming with Peltier that they take place in different parts of the cloud.

We may compare what takes place in a clap of thunder to the noise which would result from a file of soldiers discharging all their arms at the same instant; supposing the file rectilinear, and the soldiers at a yard apart from each other, an observer placed at one of the extremities of the file would hear a noise which would last for a second if there were 337 soldiers, two seconds if there were 674, and ten seconds if there were 3370. The position of the observer,

it is evident, would influence the duration of the noise and its intensity; since, according to this position, there might be several simultaneous shocks. If the file is curvilinear, instead of being rectilinear, there would, in like manner, result modifications in the duration of the sound, and in the intensity of the different shocks of which it is composed. Supposing, for example, the file circular, and the observer in the centre, the latter will no longer hear any rolling, but a very strong detonation, formed by the union of all the sounds of the muskets.

Nothing is more easy than to understand now the connection that exists between claps of thunder on the one hand, and, on the other, the length and the form of the lightning, as well as its distance and its position in relation to the observer. In particular, the zigzags, which indicate that the lightning is bent upon itself, instead of continuing to go away in a straight line, must correspond to an increase of noise, which is followed in its turn by a sudden weakening if, by a second inflexion, the lightning is led anew to move in the direction of the visual line of the observer.

Lightning therefore is followed by a rolling, because the different parts of which it is composed are in general at unequal distances from the observer; the duration of this rolling being the time which the sound requires for traversing an interval equal to the difference in length of two lines drawn to the two extremities of the flash of lightning; we shall obtain the difference in feet by multiplying the time of the rumbling expressed in seconds by 337; this product corresponds to the minimum, or to the limit of length which the flash of lightning may have, since, providing that it was its exact length, it would be necessary that the direction of the flash of lightning should be exactly that of a horizontal right line, at the extremity of which the observer would be placed. In supposing a clap of thunder, the rolling of which should last forty-five seconds, as Delisle observed in 1712, we should have for the corresponding lightning a length of 48,649 ft., or upwards of nine miles. In Abyssinia, M. D'Abbadie found, trigonometrically, lightnings of more than four miles in

length. M. Petit, at Toulouse, has seen lightnings the length of which attained to upwards of ten miles.

Although lightning is more frequently followed by the noise of thunder, it nevertheless sometimes happens that it does not thunder, even when lightnings are seen to shine forth; and this, as well during cloudy weather as with a sky perfectly serene. These lightnings, which are manifested without thunder, are called *heat lightnings*. They are generally attributed to storms too distant for the thunder to penetrate to the ear of the observer, whilst the light of the lightning still reaches his eyes. When the atmosphere is perfectly serene, it is on the horizon that heat lightnings are almost always manifested, which seems to indicate that they are, in fact, the result of the reflection in the atmosphere of ordinary lightnings, arising from very distant storms, and the direct view of which is prevented by the rotundity of the earth. We have been able, most frequently, to prove that such was actually the case, and that distant storms, which had taken place in the direction in which the heat lightnings had been perceived, were the cause of these lightnings. However, lightnings have been seen without thunder, in a perfectly serene sky, at the zenith of the place of the observation; it has occurred to several observers to perceive these lightnings during entire nights, and towards all points of the horizon equally, without the sky becoming clouded; in these cases, it is difficult not to admit that a serene sky may be traversed by direct lightnings, which dart spontaneously into an atmosphere without cloud. Might it not be that the absence of clouds was only apparent, namely, that the clouds which give rise to these lightnings were clouds so elevated and so little dense, that they are invisible? It is to the existence of these clouds, which we have already pointed out, that may be attributed, besides the falls of rain that take place in a perfectly cloudless sky, the signs of powerful electricity, which the atmospheric electrometers manifest from time to time under the same circumstances.*

* Professor Plantamour, in connection with the observations of atmospheric electricity made at the Observatory of Geneva, quotes cases in which, in a sky

The fact is, that we as yet know, only in a very imperfect manner, the mode in which aqueous vapour is distributed in the atmosphere, and that it would be very possible that, in certain moments, there may be parts of the atmosphere tolerably well defined, which may be, by the effect of divers causes, such as contrary winds or ascending currents of air, charged with more aqueous vapours than others, and thus forming invisible clouds, the presence of which would be sometimes indicated by the light of a lightning, either too distant, or occurring in an air too rarefied to be accompanied by a sensible noise. M. Peltier has proved, by many observations of atmospheric electricity, the existence of these invisible clouds.

With regard to thunders without lightnings, of which we have some examples, they are very probably due to the fact that, below the stratum of clouds in which a violent storm is taking place, there is another lower stratum, composed of very opaque clouds, which do not allow the light of the lightnings to pass, however vivid it may be. The relations of travellers confirm the supposition, that two strata of superposed clouds may exist simultaneously in the atmosphere at different heights, and a storm be manifested in the upper stratum only.

Of the Fall of Lightning: of the Phenomena that accompany it; of the Means of Protection from it. Lightning Conductors.

We have studied, in the preceding paragraph, the electric phenomena that take place during a storm, confining ourselves to those which take place in the atmosphere alone; but, as we have already remarked, the earth itself frequently participates in these phenomena; this takes place in particular when, according to the established expression, the lightning *falls* upon the earth. The word *fall* indicates

apparently perfectly serene, he drew strong sparks from the wire, which communicated with the insulated point intended for drawing electricity from the air.

that the lightning, instead of darting between two clouds, darts between a cloud and bodies placed upon the surface of the ground; it is then said that these bodies are *struck by lightning*. It does not necessarily follow that the body struck by lightning is destroyed; for there are, as we know, bodies which the electric discharge can traverse without altering them, or by altering them but very little; they are those which, either by their nature or by their dimensions or their forms, present but little resistance to the discharge; but we perceive that, as enormous discharges are here in question, these conditions are much more difficult to meet with than when the discharge of our batteries, even the most powerful, are in question. Much discussion has taken place in order to know whether lightning falls from the sky, or whether it rises from the ground towards the clouds; it has been even assumed that there are equally *ascending* lightnings and *descending* lightnings; it is evident, from the manner in which we have explained the propagation of electricity by the polarisation and discharge of successive molecules, that there is no transport of electric matter, and that consequently the lightning can neither ascend nor descend; but the arrangement and the nature of terrestrial bodies may influence the appearance of the discharge that takes place between them and a cloud, so that this discharge appears in some cases to ascend towards the cloud, whilst in others it seems to descend from it; we shall see further on examples of both cases.*

When a storm-cloud, and consequently one powerfully electrised, approaches the earth, it decomposes by induction the natural electricity of all the more or less conducteous parts that are at the surface of the ground. Its action may be arrested there if the wind brings near to it another cloud endowed, naturally or by induction, with an electricity con-

* These differences of appearance are also very frequently due to the manner in which the spectator is placed in respect to the points between which the discharge takes place. Thus, when we have discharged the conductor of a machine by means of a metal ball that is brought near to it, the spark seems to go from the conductor to the ball if it is above, and from the ball to the conductor if it is below; nevertheless, in both cases it travels exactly in the same manner; the difference, then, of appearance is a pure optical illusion.

trary to its own; the explosion then takes place between the two clouds, and the portion of terrestrial surface, whose natural electricity has been decomposed, reverts to the natural state.* But it may happen also that the discharge takes place between the cloud and the ground; in this case it will be the objects that are nearest to the cloud, among those whose natural electricity has been able to be decomposed, which will serve to transmit this discharge, and which, consequently, will be struck by lightning. These objects ought to be generally those which are most elevated above the surface of the ground; however, it may happen that in some cases, as when a storm-cloud is brought suddenly by a violent wind, the objects struck by the lightning are those which are turned on the side whence the wind and consequently the cloud comes, without their being the most elevated. Observation has in all times confirmed these results of theory; and a long time before the theory of lightning was discovered, it was well recognised that elevated places, and clock towers in particular, are principally struck by lightning.

But, whatever may be the place where the lightning falls, it tends in preference towards the conducting bodies that are found there, and towards metals; nothing is more curious than to follow its march, as we have been able to do, in many cases described by M. Arago. Thus, lightning, in falling upon a house, is seen to carry away all the gildings that are found there, without wounding the many persons who are assembled; it is seen to traverse the metal rods and wires of a house, without leaving any other trace of its passage than the fusion of the wires, whilst the rods, being greater, have suffered no alteration; then to divide itself, to traverse a barrel of a fowling-piece placed against a wall, which itself remains intact, whilst the stock is broken, and the wall pierced by a hole, where the end of the barrel was resting against this wall. It suffices that there be masses of iron, clasps, nails, disseminated in walls, in order

* We shall see further on that, even in this case, an electric phenomenon takes place on the earth, which has been named *return stroke*.

that the lightning shall direct itself there, sometimes tearing them out, more frequently producing in the walls themselves damage, more or less considerable. This tendency of lightning to direct itself in great quantity upon metals, even through thick masses of stone, will explain the apparent anomalies to the damage that it occasions; and in particular how it can happen that this damage may sometimes be concentrated in a single point, which is neither the highest nor the most exposed, but which is the one where are found united the greatest number of metallic masses. More than this; it may happen that the metal alone is touched, without the surrounding bodies being so; thus an example is quoted of two ladies, one of whom, extending her hand out of window, had a gold bracelet, which she wore, carried away by lightning, without leaving any trace, herself suffering only very slight shocks; and the other of whom, under similar circumstances, had her bonnet reduced to ashes, on account of a thin wire, which formed the bonnet-shape, and upon which the material rested; the bonnet alone was touched. These effects are analogous to those which a strong artificial charge brings about when, being transmitted through a gilded silk thread, it carries away the gilding alone, leaving the thread untouched.

After the metals, moist bodies, and particularly trees, are the first assailed by the fall of lightning; it would seem that resinous trees are, for equal heights, less struck than others, which would be due to the fact that they are not so good conductors, and consequently less susceptible of drawing down lightning; however, it is difficult to deduce this conclusion in a very certain manner from the facts hitherto observed, for they are neither sufficiently numerous, nor sufficiently simple, to inspire an entire confidence in this conclusion. It is evident also that the particular state in which the tree is found, with regard to the greater or less conducting nature of the ground upon which it rests, the greater or less depth to which its roots attain, its strength of vegetation, and consequently the abundance of sap which it contains, are so many circumstances which, independently of

its nature, must render it more or less fitted for drawing down lightning, and for conducting it.

The effects that lightning produces in falling are, except that they take place on a much grander scale, entirely the same as those which, under analogous circumstances, are brought about by an electric discharge, — *mechanical effects, calorific effects, chemical effects, physiological effects.*

We have analysed with sufficient care the mechanical and calorific effects of discharges, availing ourselves, with this in view, of the very complete study that M. Riess has made of them, so that it is not necessary to insist long upon the analogous effects that are produced by the electric discharge which constitutes the fall of lightning. Thus, the shortening of bell wires; the melting of metals, either total, when they are in thin wires, or partial, when they have much mass; the effects of heat, more decided in all places where there are solutions of continuity in the conductors; the breaking and pulverisation of bad conductors, such as the stones of a wall interposed between good metallic conductors; the inflammation of dry materials of little density, such as thin pieces of wood, heaps of straw, hay, &c., are so many phenomena which accompany the passage of lightning, and which differ only by the greater scale upon which they are produced from the similar phenomena that we have seen to result from the transmission of discharges of powerful electric batteries.* But among these different effects there are some which the fall of lightning produces in an altogether special manner, seeing that they require for their production an electric discharge of a very great intensity; they must also claim our attention for a moment.

We have plainly seen that artificial electric discharges are able to produce mechanical effects in their passage through badly conducting bodies, like piercing and breaking a pane of glass; that they can in like manner bring about the trans-

* M. Arago, in proof of the intensity with which lightning acts, quotes the example of a chain upon a ship which was entirely melted by the passage of lightning; it was 128 feet in length, and was composed of successive rods, held to each other by rings, each $\frac{1}{4}$ in. in diameter and $17\frac{3}{4}$ in. in length.

port of metallic particles reduced to an extreme tenuity, and in particular, can detach from conductors, between which they take place, a portion of the metal, very subdivided and excessively thin, but nevertheless appreciable.

M. Fusinieri, who has made a particular study of this last class of effects when they are produced by ordinary electric discharges, has proved that lightning always contains divers matters, in the state of great division, of ignition and of combustion; he has found the proof of this in the pulverulent deposits with which the fractures remain surrounded, through which the electric matter opens a passage; these deposits contain metallic iron in various degrees of oxidation, sulphur, and carbon. Although it is probable that these matters arise from the buildings which the lightning traverses, nevertheless there are cases, as those in which ferruginous spots are found upon trees struck by lightning in the open country, where it is difficult to assign to them a similar origin. M. Fusinieri thinks he is authorised to conclude, from his observations, that the atmosphere contains at every height, or at least as far as the height of storm-clouds, iron, sulphur, carbon, with which the electric spark is impregnated, and which it transports to the surface of the earth, where they come and form very thin deposits around the points struck by the lightning. But it seems to us more natural to assume that it is from the ground whence the highly electrised clouds arise that these substances are derived, for they are observed only when lightning bursts between a cloud and the earth. With regard to the great mechanical effects that are produced by lightning, such as the overthrowing of walls, the projection afar of very massive blocks of stone, and other things of the same kind, more or less remarkable by the singular circumstances which they sometimes present, they are the consequence of the species of explosion that the electric discharge brings about whenever it is obliged to traverse badly conducting bodies, through which it cannot be transmitted except by destroying their molecular structure, that is to say, by breaking them, splitting them, or causing them to burst. It sometimes happens when bodies, such as

stones, are moist, that those effects are due to the expansive force of the steam engendered by the heat of the discharge; this in particular is what takes place when trees are struck. Most frequently their trunks and their branches are divided into thin laths, sometimes even into very fine filaments in the direction of the fibres, without any trace of carbonisation; but only all these fragments are perfectly dry; the filaments remain adhering to the base of the trunk, or are dispersed in a thousand different directions;—all these effects are evidently due to the passage of the discharge through the moist portions of the tree, and to the vaporisation of the water that results from it. The transports of ponderable matter by lightning, however curious the peculiarities may be which they present in certain cases, are only an indirect consequence of the electric discharge; and we cannot deduce, as one is tempted sometimes to do, from the direction of a transport brought about by lightning, the direction of the movement of the meteor itself. The question of descending and ascending lightnings no longer remains; and we can no longer conclude, as philosophers formerly did, that a lightning is ascending because it has raised a pavement, whilst it is descending because objects have been projected from above downward, when once it is proved that all these circumstances are indirect effects of the discharge.

Amongst the phenomena that are produced by the fall of lightning, one of the most remarkable is the formation, when it traverses a sandy soil, of vitrified tubes, which have been named *fulgurites*, or *fulminary tubes*. De Saussure on the top of Mont Blanc, Raymond on the peak of the Midi, in the Pyrenees, on the Puy-de-Dôme, Humboldt and Bonpland on the highest peak of Tobuca (at the west of Mexico), had observed numerous traces of vitrification upon the rocks of which these summits are composed, and they had not hesitated in attributing them to lightning. More than this; cases have happened in which we have been able to sound to a certain depth the land upon the surface of which lightning has just fallen, and traces have been found there of very

decided fusion. With regard to fulminary tubes, some had been discovered in 1711 in Silesia; then more recently in various parts of Germany, in England, in Brazil. The fulgurites are almost always hollow; they generally descend into the sand, in the vertical direction; they possess at the surface of the ground an opening from $\frac{1}{25}$th of an inch to $\frac{3}{5}$ths of an inch; they are contracted in proportion as they go down, and often terminate in a point; the thickness of their sides varies between $\frac{1}{50}$th of an inch and an inch; their total length sometimes attains to from twenty-five to thirty feet; numerous transverse fissures divide them into fragments of greater or less length; the inner lining of the tubes is a perfect glass, smooth and very brilliant, similar to vitreous opal. It is easy to prove that a very elevated temperature is able to produce upon sand, similar to that in which these fulgurites are found, traces of fusion and an enamel, analogous to that which coats the interior canal of the tubes. The electric origin of these tubes is the less doubtful, seeing that we have succeeded in producing similar ones, but of very small dimensions, by causing the electric discharge of a powerful battery to pass through pounded glass*; and that we have, so to speak, taken nature in the very act, by discovering them in the actual spot where the lightning had been falling. Dr. Fiedler, who has been much occupied on this subject, points out two instances of this, and M. Arago cites one of the most remarkable, that which was observed by Prof. Hagen, of Königsberg, near a village at the border of the Baltic Sea. Lightning having fallen upon a birch tree, there were discovered in the ground, quite near to the tree, two narrow and deep holes. M. Hagen had the ground carefully digged around these holes: the first, which was found warm, presented nothing in particular; neither did the second, to the depth of about a foot, present anything remarkable, but a little lower a vitrified tube commenced; the brittleness of the tube did not permit of its being drawn out except by fragments of an inch and a half or two inches in length. The internal vitreous coating was

* Savart and several other philosophers had done this in 1823.

very shining, of the grey colour of pearl, and dotted in its whole extent with black points. Dr. Fiedler remarks that, at a certain depth, on digging into plains of sand in which fulminary tubes are found, there exists beds of water, which determine the fall of the lightning upon the surface of the soil by which they are covered, and which consequently explains the formation of these tubes.

Lightning produces chemical effects, analogous to those that are occasioned by electric discharges; among these effects, the most remarkable is that to which is due the odour that accompanies it. This odour, which has been compared to that of sulphurous and phosphoric vapours, is that of ozone; and it is easy to comprehend that the powerful electric discharges which constitute lightning must change into ozone a prodigious quantity of the oxygen of the atmospheric air. It is not necessary, therefore, to go elsewhere and seek for the origin of this odour, nor in particular in the very subdivided substances that the lightning transports; the more so as the lightning which bursts between two clouds produces this same effect as well as does that which bursts between a cloud and the earth, and which is also observed in the open sea.

The atmospheric air almost constantly contains ozone at various degrees of intensity; and since, as we shall see further on, we have thought we can find, in the presence of ozone in the air, some influence over the sanitary state, plans have been devised for estimating the greater or less quantity of ozone that is found in the atmosphere by means of the feebler or deeper coloration that is assumed by bands of paper impregnated with starched iodide of potassium, of which *ozonometers* have been made. It is also to the production of ozone that the presence of nitric acid and of some nitrates in the atmosphere is due, which is indicated by the analysis of the rain waters of a storm; indeed, M. Schoenbein has demonstrated that the combination of oxygen and nitrogen, which produces nitric acid, is brought about, under the influence of electric discharges, by the conversion of oxygen into ozone. M. Liebig has discovered the presence of nitric acid in storm waters, and M. Barral that of nitrate of am-

monia; this latter chemist, indeed, on analysing, month by month, all the rain waters collected during two years at the Observatory of Paris, has constantly found in them nitrate of ammonia, even for periods when it thunders but little or not at all in Paris; which, besides, is not contrary to the electric origin of this compound, for there is not a day of the year on which it does not thunder somewhere; and the clouds that are resolved into rain in Paris have traversed regions, the extent of which we are not authorised to limit. The presence of ammoniacal salts in storm rains must play an important part in the influence of these rains over vegetation; would it not also be possible that the natural nitres, which are only found in certain particular lands, owe their origin to the formation of nitric acid by atmospheric electricity? Finally, the formation of ammonia by the electric discharges that constitute lightning evidently indicates that these discharges bring about the decomposition of the water of the clouds,—an important point, upon which we shall return further on.

Lightning, like electric discharges, exercises a very decided magnetic action, and which had been proved a very long time before the discovery of electro-magnetism. Already, in 1675 and 1681, English navigators had observed the inversion of the poles of mariners' compasses, after the fall of lightning upon ships. Sometimes it is the complete destruction of the magnetism in a needle, or even its magnetisation in a direction perpendicular to or inclined to the ordinary direction, that is brought about by the fall of lightning in its neighbourhood; effects which may all be produced by artificial electric discharges, guided in various directions outside, but very near to steel needles of divers forms, and more particularly in the form of lozenges, either filled in or hollowed out, as were formerly compass needles. It is not only by modifying the magnetism of bodies already magnetised that the magnetic action of lightning is manifested, but also by magnetising masses of steel or iron which had not been so previously; there is nothing astonishing in this, from what we know of the magnetising properties of electric discharges. There have sometimes followed, either

from this kind of effect or from the former, very grave results for the sailors who, deceived by the false indications of their instruments, have been cast upon reefs, from which they thought they were receding at full sail. The magnetisation of a multitude of masses of steel dispersed throughout a ship may create powerful centres of attraction, and, without the compasses themselves having been deranged, may produce local deviations which are all the more baneful, since, in the open sea, the navigator has few means of proving the existence of them, and especially of determining their value. Another kind of disturbance, against which the navigator has also to guard himself, is that which results from the magnetisation, by a flash of lightning, of the different pieces of steel that enter into the construction of a chronometer, and particularly of the balance. Indeed, terrestrial magnetism, then, influences the movement of the instrument, as M. Duperrey had the opportunity of observing in his voyage in the *Coquille*. Sensible accelerations or retardations follow from this, which, after a certain number of days of navigation, may produce very dangerous errors in the determination of geographical longitude. We have the example of the *New York* packet-boat, which, arriving at Liverpool in May, 1847, after having been twice struck by lightning, had chronometers 33′ 58″ in advance of what they would have indicated if the lightning had not struck the fabric. This magnetism may last for a long time; it has been found to have endured for twenty-seven years in a watch, near to which the lightning had passed in its fall.*

In order to complete the examination of the effects that are produced by lightning, it remains for me to speak of its physiological effects, and in particular of the death that it produces in men or animals which are in its path. However, it

* I have observed, on making experiments with a large electro-magnet, that a pocket chronometer, which I carried about me, stopped as soon as I approached this electro-magnet; I satisfied myself that this stopping arose from the magnetisation which the pieces of steel of the compensation balance underwent; this magnetisation, unfortunately permanent, seriously deranged the instrument, occasioning a sensible retardation in its march. Much time was necessary before the magnetisation disappeared; and the best means of making it disappear was to expose the chronometer for a long time consecutively to a temperature of from 122° to 140°.

sometimes happens that they are struck by lightning without being killed, but that they receive wounds of greater or less violence. Frequently the clothes take fire, and the victims bear the trace of burns of greater or less depth; these burns are in general indirect effects of the lightning, for its direct action consists essentially in a general shock which it occasions in the body, and which brings about its disorganisation. It is essentially in the vascular system that the lightning produces wounds, in consequence of which there is an effusion of blood and other liquids, which instantaneously occasions death; it is these derangements which, as has been observed, bring about very promptly the putrefaction of the bodies in the case of deaths produced by lightning; however, the nervous system also suffers great alterations, of which we shall see numerous proofs hereafter, without there then being, in case of death, any acceleration of putrefaction.

Lightning produces upon animated bodies which it strikes considerable mechanical effects, generally in relation to the metallic parts distributed in the clothes of the individual touched; sometimes the impressions of the lightning are only superficial, and are reduced to scars; under other circumstances, the bones themselves are broken. One case has been pointed out, in which the skull of a man struck by lightning had been as if pounded by a blunt instrument. Examples have been cited in which strokes of lightning, not intense enough to produce death, had occasioned deafness or produced gutta serena, with dilatation and loss of contractibility of the pupil; generally this deafness and loss of sight are dissipated in a short time; they have at other times been seen to endure for several days or weeks. It sometimes happens that strokes of lightning, not intense enough to kill men, have the property of ridding them of diseases, with which they were previously suffering; this we shall see in the Chapter which we shall devote to the therapeutic effects of electricity, and in which we shall study in a particular manner the influence of atmospheric electricity over the living organism. Let us further add that lightning burns the hair on all parts of the body of the individual that it strikes, and generally

causes it to disappear, which is very probably due to the fact that, in consequence of their form, it is by the hairs of the head and the hairs generally that the transmission of electricity is brought about between the body and surrounding objects.

We might cite numerous cases of deaths produced by the fall of lightning, with the particular circumstances that were presented by the dead bodies of the persons struck. One of the most remarkable is that of a man killed by lightning at Zante in 1836, and upon the body of whom were found the marks of the pieces of money that he had in his pocket, where they were lying at a very great distance from the part of the body that had received the impression; an effect analogous to that which Karsten has obtained with simple electric discharges.* In general, the chance of being struck by lightning in the time of a storm, is diminished by ridding oneself of the metal articles that we may have about one; it would appear that it is not altogether a matter of indifference to wear certain clothes rather than others. In a fall of lightning that took place, July 11th, 1819, during divine service, upon the church of Chateauneuf-les-Moutiers, in the Lower Alps, and which killed on the spot nine persons, and wounded more or less eighty-two, two of the three priests who were about the altar fell seriously struck, whilst the third, who was the only one clothed in silken robes, suffered no ill.

A very important fact to remark is, that when lightning falls upon men or animals placed one after the other, either in a straight line or along a curve not closed, it is at the extremities of the file that the effects are generally the most intense. Thus, on August the 2nd, 1785, lightning fell at Rambouillet upon a stable, in which thirty-two horses were situated in single file; of thirty that were overthrown instantaneously, only two died, one immediately, and the other a short time after; now these two horses were those which occupied the extremities of the file. The 22nd of August, 1808, lightning fell upon a house of the village of Knonau, in Switzerland; five children were reading, seated

* Vol. II. p. 174.

upon a bench, in a room on the ground-floor; the first and the last fell dead on the spot, the other three only suffered a violent shock. We might multiply examples of cases of this kind, which would seem to be comprehended in the fact, that the effect of electric discharges is always more powerful where there is a solution of continuity; but what is very singular is, that in the cases with which we are engaged, the horses and the children, although one after the other, were not immediately in contact; it is true that they were very near together.

A very rare, but very curious case among the accidents caused by lightning, is that which is designated by *return-shock*, in which persons or animals may be struck by lightning at a distance from a storm-cloud; this is an effect of induction easy of explanation. Whensoever a storm-cloud is powerfully electrised, and a person is situated within its sphere of activity, the natural electricity of this person is decomposed by induction; that of the contrary name to the electricity of the cloud is attracted, that of the same name is repelled into the ground; the person is therefore found to be in a contrary electric state to that of the cloud. But if the cloud happens to discharge itself in any point, for example, upon an elevated place, or upon a tree, losing on a sudden a large portion of its electricity, it is no longer able to retain the person who is beneath it in an electric state contrary to that which it possessed itself; then the electricity of this latter is suddenly discharged into the ground; and the electric shock that results from it may be sufficiently powerful to cause death, without leaving any visible trace of alteration in the dead body; evidently, in this case, the action has taken place upon the nervous system. The following is a case of return-shock quoted by Brydone, which is remarkable. A man named Lauder, who was driving a coal cart, was killed, together with his horses, without another carman, seated upon a vehicle that was following the former, having perceived any lightning, or suffered any shock, although he saw the horses fall; but at the same moment a powerful detonation was heard further off; moreover, traces

of electricity were evident, for there was behind each wheel of the vehicle, whose horses and driver had been struck, a hole two inches in diameter, and fulgurites were formed in the ground.

It is not without interest, before occupying ourselves with the means of protecting oneself from the attacks of lightning, to form an idea of the number of persons who are annually struck by lightning in different countries. M. Arago had endeavoured to make these statistics for France; and notwithstanding that the information which he had been enabled to procure was very imperfect and very incomplete, he found that the calculation, which gives sixty-nine as the number of persons killed annually by lightning in France, is too low. M. Boudin, who has recently published a very interesting memoir upon the number of persons that fall victims to lightning, and upon the phenomena that are observed in men and animals struck *, has succeeded, by means of documents extracted from the Archives of the Minister of Justice, in showing that lightning, in the short period from 1835 to 1852, has killed not less than *thirteen hundred and eight persons* in France, which gives a mean of about six victims per month; the question here is only of persons killed, and not of those who have been merely struck by lightning. The distribution among the different months of the year of the victims that have fallen through lightning, does not give any victim for the four months of January, February, November, and December; the maximum is in June, in which, out of 103 persons killed by lightning in the year, there are twenty-two, and in August, in which there are nineteen. The maximum of persons killed by a single stroke of lightning does not exceed eight or nine. M. Boudin has extended his researches to other countries beside France; thus he has found that the number of persons killed by lightning is, at a mean, in Belgium 3, in Sweden 9·64, and in England 22. M. Poey of Havannah, who has made similar researches for the United States and for the island of Cuba,

* We shall return to these phenomena in the Chapter devoted to the application of electricity to electric therapeutics.

found for the United States a mean of 21·83 per annum, a number evidently too low, since Meriann finds 50. It is clear that no account is taken of the cases in which lightning has only occasioned wounds, not followed by death, nor of the cases in which it has set fire to houses, cases very frequent in certain parts of the United States. It would appear that animals in general are much more maltreated than the human species; perhaps this would arise from their being congregated in a larger number; M. d'Abbadie relates, in this respect, that in Ethiopia a single flash of lightning killed 2000 sheep. Very frequently, according to the remark of M. Boudin, it happens that the shepherd, the hunter and the horseman are spared, whilst the animals, the dogs and the horses are struck.

The dangers that lightning causes us to incur, are, therefore, according to the considerations which precede, sufficiently great for its being needful to direct attention to them, as much to avoid cases of death, which are more frequent than is generally supposed, which it occasions, as to place various edifices under protection from the conflagrations which it brings about in its fall. These dangers, it is true, are not the same everywhere; thus accidents arising from lightning are less numerous in the heart of large cities than in villages and in the open country; they are much more frequent on elevated places than in the plains; certain localities of equal heights are more exposed to it than others. According to M. Boussingault, for example, on account of the frequency of the fall of lightning, no one willingly inhabits El Sitio de Tumba Barreto, near the gold mine of Vega de Supia, in the Republic of New Granada. La Loma de Pitago, in the environs of Popayan, has the same celebrity. If the number of persons, who fall victims to lightning, is not considerable in the heart of cities, the number of houses and buildings, that are struck and damaged, is on the contrary very great, as follows from the census that has been made of them by M. Arago. He points out the considerable damage that is the consequence of them, and in particular, that which is occasioned by lightning, when it strikes powder magazines and ships. He quotes a great number of examples of both

cases; and he remarks that it sometimes happens that lightning, in penetrating into powder magazines, disperses the powder without setting it on fire. This fact, rare however, for the inverse is much more frequent, is due to the circumstance that the inflammation of powder, as we have seen, takes place only so long as the electric discharge encounters in its route a certain resistance, which retards its velocity.

Man, from the most remote ages, has therefore devised means for protecting himself personally from lightning. We will not examine these various methods, which have only an interest that is purely historical; we shall confine ourselves to remarking that, among these means, some possess no value, and others, such as not to run, to prevent currents of air, &c., have all at least a doubtful value.

Although an insulating envelope certainly mitigates the danger with which one is threatened, as is proved by the example that we have cited, of a priest who was preserved from the attack of lightning by the silk vestment with which he was clad, nevertheless we cannot admit that it causes it altogether to disappear; indeed, glass itself is not always respected by lightning, as is proved by several examples of panes of glass broken and reduced to powder by it, and even simply pierced by very defined holes, without adjacent fissures. We have already said that it would be better to avoid having about one metallic objects, when fearing to be struck in the time of a storm. Franklin also recommends not to keep oneself too near to chimneys, the soot of which is able to conduct the electric discharge; to keep oneself distant, for the same reason, from metals, from looking-glasses (on account of their tin-foil), from gildings. The best thing appears, that we should endeavour to keep ourselves in the middle of a room; the less we touch the walls and the ground, the less are we exposed; the surest plan perhaps would be to have a hammock, suspended by silk cords in the centre of a large room. However, even with these precautions, it may happen that, if the lightning does not find a continuous conductor around the chamber, it may dart from one point upon the point diametrically opposed,

and may meet in its course the person placed in the middle of the room. Numerous assemblies of men or animals may increase the danger of being struck by lightning, either by assembling in a given point a greater quantity of conducting matter, or by producing, from their breathing, an ascending column of vapour, the effect of which is to conduct in preference the discharge toward the place itself whence it emanates; finally, it is probably also to an ascending current of moist air, that may be attributed the fact, observed very generally, that granaries filled with grain and forage are more frequently struck by lightning than other buildings. It also sometimes happens that a single person is struck in the midst of a numerous group; and, inversely, that a single person is spared, without our being able to detect any exterior cause of this difference, which is evidently due to the circumstance that, as is proved by direct experiment, there are individuals who are naturally better conductors of electricity than others.

Although it would be more prudent not to be situated in the midst of clouds, out of which lightning and thunder are escaping in an incessant manner, yet a great number of examples of persons who have been placed in this situation, and who have come out safe and sound, show that there is not always danger of death in traversing similar clouds; it is in like manner more prudent, in the time of a storm, to keep oneself at a certain distance from telegraphic wires, in order to escape the shock of the sparks that may result, as Professor Henry has demonstrated, from phenomena of induction.

It is not only individuals, but buildings, entire towns, and even great extents of country, that we have endeavoured to preserve from lightning, by various processes. It was first proved that, when a storm passes over a vast forest, it is notably weakened; which is due to the fact, that the trees draw from the storm-clouds a considerable part of the electricity, with which they are charged. We have the proof of this, moreover, in the multitude of cracks or fissures that are found in them when they are sawed to make planks or boards of them — fissures that evidently arise from the strokes of

lightning which they have suffered. Nevertheless, trees are not always preservatives against the dangers of lightning, although they are most frequently so; examples are quoted of houses struck, although they were commanded by trees very near and much more elevated than they; which is very probably due, as we have been able to prove in many cases, to the fact that the ground upon which the trees were, was a much less good conductor than that upon which the houses rested. It has been for a long time thought that large fires lighted in the open air, by drawing off electricity from the clouds, or strong and numerous detonations of artillery, by dissipating storm-clouds, were efficacious means of preserving surrounding places from the effects of storms; it would appear that the former of these means is not altogether inefficacious. With regard to the latter, the observations collected by M. Arago, on a tolerably great scale, seem to demonstrate that it is without any species of influence. It is the same with the act of sounding or not sounding bells in the time of a storm; it is in no way proved, as results from very complete statistics, that the sound of bells increases or diminishes the imminence of danger from strokes of lightning; only we must avoid raising the bells, for the sake of the ringers, for the danger which they run is the same as that of the imprudent, who, in the time of a storm, take refuge under large trees. Lightning strikes elevated objects, and especially the summits of bell towers; the hempen cord attached to the bell, generally impregnated with moisture, conducts the discharge as far as the hand of the ringer; hence so many deplorable accidents.

After this rapid sketch of the means by which endeavours have been made at various times to gain protection from the attacks of lightning, we arrive at modern lightning conductors, such as Franklin contrived them, and which have been perfected since his time. Their efficacy, which has been confirmed by facts, flows at once from observation and theory. Observation has taught that lightning, in general, is directed upon the most elevated parts of buildings, that it directs itself in preference upon metals; that, when once

it has penetrated into a metallic mass, it does not produce damage until the moment of its escape and around the points by which this escape is brought about; that, finally, the moist earth presents to the lightning an easy escape, which is not accompanied by any damage, when the metal which contains it plunges a little deeply into the ground. Hence it follows, that a house will be protected from its roof to its foundation, if there are found in it culminant points pieces of metal, which from the roof are prolonged without solution of continuity as far as the earth, and abut there by burying themselves in the ground, always more or less moist. When there are on the roof of an edifice several metallic masses, completely separated from each other, it is difficult, and even impossible, to know which of these masses will be struck by lightning in preference; for the point of departure of the storm-clouds, the direction and the velocity of their propagation must have, in this respect, a marked influence. Thus the best means of getting out of the difficulty is, to unite all the separated masses by metal bars or bands, so that thus they all communicate with the base that abuts on the moist soil.

The efficacy of these means, borrowed from observation alone, explains why houses, furnished with continuous metallic roofs, communicating with the ground by the intervention of water-spouts, likewise of metal, are almost generally spared by lightning, whilst it is not the same with other houses. We find, in this fact, an explanation of the very remarkable difference that exists between towns and villages, with regard to the number of persons struck by lightning, the houses of towns being almost always in the former category, and those of villages in the latter. It is to the same cause that must be attributed the fact, already pointed out by De Saussure, that the towers of the cathedral of St. Pierre at Geneva, although very elevated, and placed on an eminence, so as to command all the objects situated in the environs to a great distance, have enjoyed for nearly three centuries the privilege of never being struck by lightning, whilst the much lower bell tower of Saint Gervais has been frequently

struck by lightning. In point of fact, the towers of Saint Pierre are protected by accidental conductors; that of the middle in particular, which has existed for nearly 300 years, being entirely of wood, was required to be covered with tinned iron from top to bottom, and its wide base, communicating with all parts of the edifice, meets with numerous pieces of metal, which themselves abut upon pipes of lead and tinned iron, that penetrate into the ground to which they conduct the rain-waters. The high column of London, called the Monument, raised in 1677, in commemoration of the great fire in that capital, although 200 feet in height, has never been struck by lightning since it has existed; which is evidently due to the fact, that its upper part is terminated by a large metal basin, furnished with a great number of bands, also of metal, which, turned in various directions, and being intended to represent flames, are all terminated in very fine points; the basin communicates with large bars of iron, and by their intervention with the balustrades, also of iron, of the staircase that descends down to the ground; all this collection forms a perfect conducting system, very fitted to give an easy and natural escape for the discharges of storm-clouds that arrive in the neighbourhood of the summit of the column. It would be easy to multiply similar examples. We may, then, conclude that one of the best means of protecting an edifice from lightning, is carefully to furnish its roof with metallic bands (tinned iron, zinc, lead), taking the precaution that there is no solution of continuity between them, and making them all communicate metallically with the earth, by means of rods of iron, or even by means simply of the spouts of tinned iron, of zinc, or of lead, intended for conducting the rain-waters into the ground; only this precaution must be taken, that these rods or tubes penetrate sufficiently deep into the ground, and abut upon the moistest parts.*

* One portion in the tube, less conducting than the rest, is enough to annihilate or to weaken the preservative effect of this system of conductors. I have myself made the experiment upon a farm-house, the roof of which was furnished with tinned iron, which communicated with the ground by a spout, of which a portion was in the ground; lightning struck a tin ball placed on the metal

The theory with regard to the efficacy of the means that we have been pointing out, is completely in accordance with observation. It is evident that, when a storm-cloud approaches an object placed upon the ground, it electrises it by induction, driving into the ground the electricity of the same nature as that with which it is endowed, and preserving to itself that of the contrary nature. When the cloud has arrived at a certain distance from this object, the two opposed electricities tend to reunite, and this reunion is brought about in the air beyond the object; if the latter, being a conductor, and having a good electric communication with the ground, the electricity has been able to propagate itself in it freely and without obstacle; whilst, if the body is a bad conductor, wholly or in part, it serves itself as a passage for the reunion of the two contrary electricities, accumulated one in the cloud, the other by induction in the ground; and it suffers in consequence mechanical and calorific damage, which in this case takes place.

But theory goes further: it suggested to Franklin the idea of placing upon the summit of buildings, in order to preserve them from lightning, pointed metal rods tolerably elevated, placed in communication with the ground by means of conducting rods of sufficient dimensions to be neither heated, nor consequently melted by the passage of the electricity; it is this system of conductors thus arranged, that constitutes lightning conductors. The utility of these arrangements follows from the analysis of what takes place in the preservative action of lightning conductors; in point of fact, when a storm-cloud passes above a lightning conductor, it acts upon its natural electricity, and by its intervention, upon that of the earth; it draws down the electricity of the contrary name to its own, which, escaping easily by

ridge of the roof, but it occasioned a powerful explosion, leaving traces of fusion on the ball, which it had pierced, and dispersed itself into the ground, breaking the part of the spout that was in the ground; there was no other damage, but it is evident that the explosion was due to the resistance that the discharge had encountered in that part of the non-metallic spout; for having from that time (twenty-five years ago) caused the metal ridge of the roof to communicate directly with the ground by a metal rod, the accident that took place was not renewed.

the point, goes to neutralise the latter, at the same time that that of the same name is repelled into the ground; the cloud is thus found, if not totally, at least partially discharged, and consequently becomes inoffensive. But, in order that this process may be freely accomplished, it is first of all necessary that the conductor should communicate very well with the ground; if not, it will become charged itself with the electricity of the same name as that of the cloud, and may give rise to very dangerous explosions; the form of a point, given to the upper extremity of the rod, has the advantage of extending the sphere of activity of the lightning conductor, because the electricity of the contrary name to that of the cloud, being able to pass away much more easily, it will be able to discharge the cloud at a greater distance, and consequently over a greater extent. However, the former of the two conditions is much more essential than the latter; for, if the conductor is imperfect, or presents some solutions of continuity, the lightning, instead of traversing it, will run the risk of being carried laterally upon the neighbouring conducting bodies; and the lightning conductor will become much more hurtful than useful; since it will possess the inconvenience of drawing down the lightning, without having the advantage of nullifying its dangers. When the conducting rod of a lightning conductor presents a solution of continuity of a small fraction of an inch, at the approach of a storm-cloud, a succession of brilliant sparks are seen, forming, as it were, a torrent of light, escaping between the two disjointed portions of the conductor; but if the space that separates them becomes more considerable, the sparks cease to be continuous, and they are replaced by a succession of powerful discharges, which present the risk of being diverted laterally.

The second condition, that of terminating the rod in a point, is not indispensable; only when it is not fulfilled, namely, when the point is blunted, or a ball is substituted for it, it sometimes happens that it is by an explosion, and not by a continuous current, that the electricities of the rod and of the cloud unite; but the discharge of lightning no

less follows the conductor into the ground, and makes no ravage in the building. The only inconvenience that takes place in this case is, that the extremity of the lightning conductor undergoes a commencement of fusion, which runs the risk of being impaired. Moreover, this inconvenience is equally presented, and in a higher degree, with a pointed lightning conductor, in consequence of the small dimensions of its extremity, when a storm-cloud driven by the wind, arriving suddenly in its vicinity, discharges itself at once, and not by the gradual escape of the contrary electricity, emanating from the extremity of the lightning conductor. However, when the clouds travel slowly, well constructed pointed lightning conductors possess the advantage of drawing away from those, which pass within their sphere of action, their electric character, as several observers have frequently remarked.

The construction of lightning conductors has been very frequently the subject of examination by learned bodies. The Académie des Sciences in particular has published successively on this subject two instructions; one, in 1823, drawn up by M. Gay Lussac, the other in 1854, supplementary to the former, drawn out by M. Pouillet. These instructions enter into many details upon the different parts, of which a lightning conductor is composed; there is first the upper rod, which is a bar of square or round iron, made thinner from the base to the summit, and which, for 23 to 30 feet in height, has a base of 2 or $2\frac{1}{4}$ inches in width. If the rod, in consequence of its length, is composed of two parts, it is necessary that these two parts should be fitted exactly one into the other; and it is good to solder with tin all the joints, for fear that rust, by introducing itself into them, should bring about a breach of continuity. It should be the same for the joints of the iron bars, $\frac{1}{2}$ to $\frac{3}{4}$ inch square, which, connected end to end, form the conductor intended for uniting the base of the vertical rod with the ground. The point of attachment between this base and the conductor should be at a certain distance (4 to 8 inches) above the roof; it is made by means of a metal collar hinged, which envelops the vertical rod

for an extent of 2 inches, and which carries two lips, against which the extremity of the conductor is pressed hermetically. Care is generally taken to maintain the conductor, in its whole course, at a certain distance from the roof, from the cornice, and from the wall of the building, by means of cramps placed at regular distances. As soon as it reaches the ground the conductor is led into a well, if there exists one in the vicinity, in which the water is permanent; in order to multiply the contact, it is led to the well by trenches dug in the earth, which are carefully filled with baker's braise, which is a very good conductor, and preserves the iron from rust. If there is no water, a moist and deep place is sought for, and the conductor is led into it by a very long trench, in which it is well enveloped with braise, care being taken, for greater security, to form trenches perpendicular to the first, and of greater or less length, into which ramifications of the conductor are made to pass; moreover, it is well, even when it does abut into water, to let it arrive thither, by dividing it into several branches.

The Academy had recommended, in its first instruction, to compose the upper rod of the lightning conductor of three pieces: an iron rod, surmounted by a copper rod, itself terminated by a gilded copper or a platinum point, in order to avoid the alteration that a point, made with an oxidisable metal, would suffer with time. The instruction of 1854 returns to advise a copper point, seeing that copper being a much better conductor of electricity than platinum, it is less heated under the action of this agent, and consequently runs less risk of being altered by fusion, which frequently happens to the platinum points. It is likewise necessary, with a view of avoiding this inconvenience, whatever the metal may be of which the point is made, not to make it too pointed. A conical point, under an angle of 30°, is in this respect entirely suitable; it is true that we lose a part of the action by induction, exercised over a storm-cloud; but, on the other hand, we gain more than we lose, by the incomparably greater resistance that is opposed to fusion and to disintegration by lightning by a point which, instead of being drawn

out, is pointed only within the limit indicated. We even think that, in this respect, a small sphere of gilded copper would perhaps be preferable; for it would resist still better the destructive causes; and its radius of activity would not be much less than that of a point, but little sharpened. It would also possess the advantage of exercising its influence in all directions, which would be valuable in cases that are not rare, in which the lightning comes and strikes the buildings laterally.

It has been very generally admitted that a lightning conductor could effectively defend around it, from the attacks of lightning, a circular space of a radius double its height. This rule is also applied in practice in furnishing buildings with a number of lightning conductors, depending upon their length and width; the same conducting rod may be subservient to two lightning conductors; and, in general, when there are several lightning conductors upon a building, it is well to make them part and parcel of each other, by causing them to communicate together by conductors. With regard to the rule, relative to the height, it is far from being absolute, for it varies with the form of the extremity of the lightning conductor, with the nature of the building, &c.

Ships having been very frequently struck by lightning, as much because they are alone in the open sea, as because they communicate with the very conducting sea-water, care has been taken to furnish them with lightning conductors. In general, there is adjusted to the extremity of the head of the fore-topgallant mast, a copper rod of a foot or so in length, including its point; and it is made to communicate, by means of a copper cable, with the sheathing of the vessel. Copper is preferable to iron, in that it is much less alterable in the air, and in that, being a better conductor, a section much less in size may be given to it; it is sufficient for the cable to have a section of about half an inch square. Sir W. Snow Harris, who has been much occupied with the dangers that lightning causes ships to encounter, has conceived the idea of rendering strong metallic conductors an integral part of the masts and the hull of the vessel. He accom-

plishes this object by incorporating with the masts and the keel a series of plates of copper, so arranged that they adapt themselves to all the variable positions of the masts; they are so united together, that an electric discharge striking the ship, no matter in what point, cannot enter into a circuit of any kind, of which the conductor would not form a part. The ship is thus preserved from lightning, without its manœuvres being hindered, and without the rigging requiring to be interfered with in any manner.*

In terminating this section, it is impossible for us not to inquire if it is actually well proved that lightning conductors have preserved from the ravages of lightning the buildings upon which they had been erected. M. Arago cites several cases, which leave no doubt upon the affirmative reply that must be given to this question. There exists in Carinthia, at the château of Count Orsini, a church placed upon an eminence, which was so frequently struck by lightning, that the end was, that divine service was no longer celebrated there in the summer. In 1730, a single flash of lightning entirely destroyed the bell tower; after it was rebuilt, the meteor continued to strike it four or five times a year, without reckoning the cases of extraordinary storms, during which five or even ten lightning strokes reached the bell tower in a single day. In 1778, the building was reconstructed, and furnished with a lightning conductor; in 1783, according to Lichtenberg, namely, in a space of five years, the bell tower had received only a single stroke of lightning; and this stroke had fallen on the metal point, without producing any damage. Since its construction, the church of St. Michel, at Charlestown, was visited and damaged by lightning every two or three years; a lightning conductor was placed there; during a period of fourteen years, from the establishment of the lightning conductor, the church had not been struck any more. The bell tower

* We regret being unable to give more details on the very interesting works, both in the theoretical and in the practical point of view, that Sir W. S. Harris has produced upon the mode of erecting lightning conductors upon ships; but this very special subject would lead us beyond the limits that we have prescribed to ourselves.

of St. Mark at Venice, elevated 333 ft. above the ground, was frequently attacked by lightning, which was dependent on its great elevation, and its isolated position, and the multitude of pieces of iron that enter into its construction; it was armed with a lightning conductor in 1776; from that time it has not been damaged by lightning. To the examples that we select from among many others, we must add those which show that when, in the midst of several similar buildings, there are some which are armed with lightning conductors, these latter alone are spared by lightning under similar circumstances. Sir W. Harris cites the case of six churches in Devonshire, surmounted by high bell towers, all of which, in the short space of a few years, have been struck by lightning, and of which one alone, the only one that was armed with a lightning conductor, had been so without suffering any damage. It is especially in ships that we find the differences between those which are furnished with lightning conductors, and those which are not; thus, in 1814, lightning having fallen in the port of Plymouth, a single vessel was struck and damaged; this was the only one which, at that moment, was found not to have a lightning conductor.

By the side of this, it is true, are cited cases of buildings furnished with lightning conductors, that have been destroyed or damaged by lightning; but there is not one of these cases in which defects of construction have not been recognised of a nature to explain the cause of the accident; it is essentially in the imperfection of the conductors, or in their mode of communicating with the ground, that these defects are found. Thus, the flash of lightning that on February 23rd, 1829, struck the powder magazine of Bayonne, and so seriously damaged it, although the lightning conductor with which the building was furnished had been constructed according to all the rules laid down in the "Instructions of the Académie des Sciences," in 1823, was due to the circumstance that the metal bar, serving it as a conductor, instead of plunging into the water of a well, or of being found in contact with moist earth on a large scale,

was sustained horizontal throughout its course, at a height of two feet and a half above the ground, by wooden posts, that is to say, by imperfect conductors, and plunged vertically into the ground only about a couple of yards. It is true that the extremity of the bar had been enveloped in charcoal; but, instead of being quenched braise, it was only ordinary charcoal, a poor conductor. It is not, therefore, astonishing that, not finding a sufficient escape by the way that had been provided for it, the lightning had followed the direction of the five posts in order to arrive at the ground, and that in certain points it darted upon the more moist portions of the wall. In June, 1819, lightning fell upon the principal pinnacle of the cathedral of Milan; this pinnacle was armed with a lightning conductor in good condition, the conducting rod of which plunged into a vast cesspool; nevertheless, near to this conductor, which was entirely intact, pieces of marble, &c. were found at various elevations broken and dispersed; Prof. Configliachi proved that the pretended cesspool was only a flagged cistern, and which consequently did not communicate with the ground. Lightning fell Jan. 4th, 1827, upon the lightning conductor of the lighthouse at Genoa; this lightning conductor, and the conducting rod, were broken in several points; but it was discovered that the water, into which the conductor plunged, was contained in a cistern, hollowed by the hand of man in the rock upon which the lighthouse rested.

We may inquire, when we see the dangers to which we are exposed by some negligence or some imperfection in the construction of lightning conductors, whether it would not be better to do without them, than to run the risk of drawing down the lightning, without being sure of being able to preserve ourselves from its attacks. We must, however, remark that, when lightning falls upon even imperfect lightning conductors, it never occasions so much damage as when there are no lightning conductors. However, we conceive that, perhaps what would be preferable in all cases, would be, to make it a rule to cover the ridges of the roofs with sheets of tinned iron, taking care to make

them communicate well with each other, and with the water-spouts, and taking the precaution of plunging these latter a little deeply into the ground, so as to establish between them and the moist earth or the water, situated in the neighbourhood, a good metallic communication; cables of copper wire are very convenient for this; and in default of them, we may make use of thick iron wires.

Of the Part played by Atmospheric Electricity in Meteorological Phenomena.

We have, in the preceding paragraphs, studied the immediate effects of the electricity of the atmosphere, which, under the name of lightnings, thunders, and strokes of lightning, are, with the exception of their intensity, the same as those that are produced by artificial electric discharges. But atmospheric electricity plays, in meteorological phenomena, a part which is not thus limited; it is so intimately united with these phenomena, that there is not one, so to speak, in which it does not show itself either as a cause or as an effect, or simply as a concomitant. The precipitation of dew, the formation of fogs, the fall of rain, that of snow, are always accompanied by electric manifestations; but it is especially in the production of hail, in the appearance of water-spouts, that the part played by electricity is manifested in a very decided manner. It is equally evident, in certain luminous phenomena which, without possessing the characters of lightning, are not the less electrical, as we shall see by the rapid examination that we are about to make of it.

The ancients designated, under the names of Castor and Pollux, a bright light with which, in stormy weather, the salient portions and principally the metallic parts of bodies sometimes shine. At the present time these fires are more generally known under the name of St. Elmo. They may sometimes acquire enormous dimensions, as follows chiefly from the recital of sailors. In 1696, at anchor off the Balearic Isles, during very dark weather, accompanied by frightful lightnings and thunders, Forbin relates that they

saw on the ship that it was surmounted by more than thirty St. Elmo's fires; there was one in particular, on the top of the vane of the mainmast, which was half a yard in height. A sailor, having climbed to the top of the mast, related that the fire made a particular noise, which, according to the description that he gave of it, appeared to be in every respect similar to that which is made by electricity, when it escapes into the air under the influence of a powerful tension. The sailor, having removed the vane, immediately saw the fire leave it to transfer itself to the top of the mast. Many cases are cited, in which soldiers, especially cavalry (which is due to their being more elevated) have seen fires shining on the points of their lances, and their swords. But it is especially in time of storm that these fires are seen on the summit of clock towers, and of elevated places in general. Watson relates that M. Binon, curé of Plauzel in France, observed for twenty-seven consecutive years that, during great storms, the three points of the cross of the bell tower of his church appeared enveloped in flames. Although, in contradistinction, there are very elevated places that never present these appearances, it is probable that it is due to want of observation, their having in general been so little remarked upon the salient parts of ships, at the point of bell towers, or upon the rods of the vanes, and the lightning conductors placed upon the summits of houses. Besides, a sufficient number of them have been observed to have enabled us to point out differences between these lights, not only in respect to their intensity, but also in regard to their forms; thus, although most frequently they resemble brushes, nevertheless it also sometimes happens that their light is found concentrated into a small globe, without any trace of diverging jets. But it is not only at the extremity of objects placed upon the earth that luminous appearances are perceived in times of storm; it sometimes happens that rain itself possesses a phosphorescent light. It is the same with snow and hail; but it is snow which, of these three forms of aqueous precipitation, appears most frequently to present this phenomenon, which is besides not due to the aqueous nature of the precipitations,

but rather to their being charged with electricity; for the fine dust that fell over the city of Naples, during the eruption of Vesuvius in 1796,—an eruption accompanied by the very remarkable electric effects that we have already pointed out,—emitted a pale, phosphorescent light, very visible at night. In like manner, the famous dry fog of 1783, which covered almost the whole of Europe, and which very probably had a volcanic origin, diffused by night a light which enabled one to see objects at a certain distance; and which likewise extended over the whole horizon. Many cases have also been observed of ordinary fogs, which are phosphorescent—in Ireland in particular. The clouds themselves may be sometimes luminous in a continuous manner; it is especially in the winter nights, and during snowy weather, that this luminous appearance is manifested; the clouds, charged probably with snow, diffuse in all directions a reddish light, without defined limits, but, according to Beccaria, sufficiently intense to enable one to read books printed in ordinary characters. The electric property of snow is, in fact, so decided, that not only, as we have seen, are atmospheric electrometers charged very powerfully during the fall of snow, but very frequently people, who are in the midst of these falls, themselves become a focus of electricity. This electricity is not only manifested by a light, but by a particular whizzing; thus Brewster cites the case of two English travellers, who, surprised in their descent of Etna by a heavy fall of snow, accompanied by violent claps of thunder, heard a hissing noise every time they extended their arms into the air, and leaving only one finger of the hand extended; but, on moving the finger through this snowy atmosphere in various directions, and with rapidity, they were able at pleasure to generate a great variety of musical sounds, the intensity of which was such, that they were perfectly heard at the distance of some fifteen yards. It is highly probable that the very remarkable phenomenon, known under the name of aurora borealis or polar aurora, arises likewise from luminous electric discharges which take place between the icy particles suspended in the air at great heights, in which they form very light

clouds. But as the phenomenon of the aurora borealis is intimately connected with the direction and variations of the magnetised needle, which would seem to establish between these two classes of facts a mutual dependence, we shall defer what we have to say concerning it to the following Chapter, which is devoted to the study of Terrestrial Magnetism.* It is also to the icy particles which, suspended in the high regions of the atmosphere, form *cirrus*, that must be attributed an important part in the formation of *hail*.

Under the name of hail is designated the fall of small masses of water, frozen very compact, to which the name of *hailstones* is given; these hailstones are nearly of the size of a hazel-nut; they are frequently of greater bulk, often also they are less; and when they are small (about the $\frac{1}{10}$th or $\frac{1}{12}$ of an inch in diameter only), they are designated under the name of *sleet*; they have evidently the same origin, and sleet must be distinguished from hail no further than the fine snow which, in the cold days of winter, sometimes floats in the atmosphere, is distinguished from the large flakes that fall in moist days. The grains of sleet are opaque, often rather hollow, and of a whiteness similar to that of snow; the larger are sometimes surrounded by a slight coat of ice; they generally fall in winter and in spring, and they rarely accompany storms. Hailstones, on the contrary, only fall during storms; their fall is always accompanied by considerable electric manifestations in the atmosphere. They are composed of a snowy nucleus, always surrounded by a coating of ice of greater or less thickness, itself sometimes transpierced here and there with small snowy flakes. The true form of hailstones is not spherical; it is rather that of a pear, and it is probable that the pyramidal is their primitive form. It has frequently been said that the coating of ice which covers the snowy nucleus is formed of concentric coats, which would indicate a successive formation; however, some philosophers,

* We do not here speak of ordinary phosphorescence, which is probably an electric phenomenon, as we have remarked (Vol. II. p. 332.); but the theory of phosphorescence is not yet sufficiently advanced for us to be able to classify either the facts which are related to it, or those which depend exclusively upon electricity.

and especially M. Bois-Giraud, who has carefully described a violent storm of hail of which he had been a witness, was not able to find the slightest trace of concentric coating in the numerous hailstones that he submitted to a minute examination, which seems to indicate that they are formed by a single operation; other philosophers affirm, on the other hand, that they have recognised, in the congealed mass that surrounds the nucleus, distinct coats, sometimes transparent, at other times alternately transparent and opaque; but they acknowledge that there exist hailstones in which this structure is not found, and in which it is replaced by a structure radiating from the centre. On the other hand, all hailstones that have been examined have a snowy nucleus of a variable diameter; and several among them present, in addition, similar small nuclei, but of only $\frac{1}{8}$th of an inch in diameter, which are imbedded in the outer and transparent part of the hailstones; this circumstance, added to the frequent flattening of the central snowy nucleus, and to the intimate union of several hailstones into a single one, seem to indicate that these hailstones have been liquid, or at least moist. We will return to this important observation. Let us add that the exterior of hailstones is very angular; several present sharp points of $\frac{3}{4}$ths of an inch in length, and even more. M. Bois-Giraud has found, in the interior of some of the hailstones that he has examined, a grey and pulverulent matter; this fact appears well established, although it has been disputed, but it is very rare.

The size of hailstones is very variable; M. Bois-Giraud, in the falls of hail that he has observed, has found some which, when deprived of their asperities, had the dimensions of a good-sized hen's egg; but these were the most bulky. M. Olmsted says that, in America, there fall every year some that are larger than hens' eggs. Generally, however, the largest hailstones do not exceed the size of a pigeon's egg. Different philosophers cite the case of hailstones which weighed from $3\frac{1}{2}$ oz. to $4\frac{1}{2}$ oz.; it is stated that some fell at Constantinople, in 1831, which weighed $17\frac{3}{4}$ oz.; some hailstones have even been mentioned of the weight of nearly $4\frac{1}{2}$ lbs.

But it must be borne in mind that these are very probably agglutinated hailstones, which must not be confounded with the simple hailstone.

It would be very interesting to know exactly the temperature of hailstones at the moment of their fall; M. Pouillet, who is the only observer within our knowledge who has thought of this, has found that this temperature was comprised between 1° and 7°, below 32°; we may, therefore, affirm that their temperature is very little lower than that of melting ice.

Hail falls at all hours of the day; and it is not correct that it does not fall in the night; but it follows, from the lists made by M. Kaemtz upon the hail fallen in Germany and in Switzerland, that it is a little after noon, and toward the moment of the greatest heat of the day, that hail falls most frequently, particularly in spring and in summer. It is, in fact, in summer, at least in the interior of Europe, that the greatest part falls, the half at least of the total number of hail-falls. In England, on the contrary, the number of falls of hail in summer is very small; in France, it is in the spring that sleet, known under the name of *giboulée*, is very frequent; but hail, properly so called, is there, as in the rest of central Europe, more frequent in summer.

The influence of localities upon the frequency of the fall of hail appears incontestable; nevertheless, we have as yet in this respect nothing but vague notions. Several philosophers, and among others, M. De Buch, are disposed to believe that hail is not so common in elevated regions as in the lower. However, M. de Saussure, during his sojourn of thirteen days upon the Sol du Géant, at the height of 11,000 feet, was struck by the frequency of hail and sleet, which he observed eleven times. Many hailstones are found beneath the snow that covers the summit of Mont Blanc. These facts and others beside prove to us that frequently on the summit of the Alps there falls, if not always hail properly so called, at least sleet, which is transformed in its fall, sometimes into hail, and frequently into rain, according to the temperature. M. de Charpentier, from numerous observations made at Bex,

is altogether disposed to regard the large drops of rain that fall during storms as melted hailstones.

It appears that it is the same in the tropical regions, and that the rarity of falls of hail in the plains is due to the fact that the hailstones melt also in their fall; for hail becomes more common at from 1600 feet to 1900 feet in height, according to the observations of M. De Humboldt and of some other travellers. There fell, on August 17. 1830, hail so abundant in Mexico, that in the streets of the city the horses had it halfway up their legs.

Independently of the absolute height and of the latitude, it follows, from many observations, that various local circumstances, such as the configuration of the ground, have an influence over the frequency of the falls of hail; thus certain countries are frequently ravaged by hail, whilst others very near to them are so but very rarely. In Switzerland it has been observed that the valleys which run from east to west, such as Le Vallais and the canton of Glaris, remain a great number of years without being attacked by the scourge. According to M. Despine, who has made a very exact list of all the falls of hail during the year 1840, in the states of the King of Sardinia, the direction of the hail is dependent in each locality on the chains of mountains that command them; but every time that it has attacked on the same day several provinces frequently very distant, and situated on the two declivities of the Alps and the Apennines, it has constantly followed one or more lines, directed from the south-west to the north-east. In general, hail is very common at the entrance of valleys, where they are confounded with the country called the plain, in opposition to the high Alps. Thus Borgo Franco, at the entrance of the valley of Aosta, is devastated by hail almost every year; and even De Saussure had remarked that countries situated at some distance from high mountains are afflicted by this scourge more frequently than those which are placed at the very foot of the Alps, or at a great distance from mountains. It is evident that the unequal heating of different parts of a valley, and the currents of air that result from it, have, as well as

the direction of the winds, both local and general, a great influence over the frequency of the falls of hail; this frequency also is much greater in the countries of deep valleys where considerable differences of temperature can be established, and much less in countries of the plain; hail is, from all that is apparent, more rare on the open sea, where continual currents of air re-establish the equilibrium of temperature as soon as it is broken.

Although most frequently storms of hail are very limited, yet there are cases in which they extend very far; but even in these exceptional cases, it is in length and never in width that the fall of hail has its greatest dimensions. One of the most remarkable cases is that of the famous hailstorm that traversed France and Holland, July 13th, 1788; it was propagated simultaneously along two bands, very nearly parallel, both directed from south-west to north-east. The first, more narrow, had a mean breadth of about two leagues and a quarter; the second, a mean width of three leagues; they were separated by a band, which received merely an abundant rain, and of which the mean width was five leagues and a quarter. There was also much rain on the west of the western band, and on the east of the eastern band. Along a length of more than a hundred leagues for each band, there was no interruption in the storm; and it even appeared that it covered still more than fifty leagues to the south-west, and fifty leagues to the north-east, which gives to each band a total length of 200 leagues, or about 621 miles. In this immense extent all points were not assailed at once, but it was noticed that the storm had had a very rapid progress from the Pyrenees, where it took its rise, to the Baltic, where the traces of it were lost; its velocity was about sixteen leagues and a half per hour. In each place the hail did not fall longer than seven or eight minutes; the hailstones differed in form and in dimensions.*

We see, by this example, that if the storms of hail are

* The ravages that were caused by this storm were considerable, as may be supposed; there were in France 1039 parishes devastated, and the damage which they suffered was estimated at 24,690,000 francs (987,600*l.* sterling).

more rare in the countries of the plain, they are in general much more widespread there than in the mountain countries, where the hail-falls, more frequent it is true, are much more local. Thus one of the most violent storms of hail that have been well observed, is that of Aug. 23rd, 1850, in which, according to the information collected with great care by M. Blanchet, the column of hail, setting out from the summit of the Jura about three o'clock in the afternoon, arrived at Fribourg at half-past four, after having traversed eighteen leagues in an hour and a half, being directed from the south-west to the north-east. According to M. Blanchet, hail, in the canton of Vaud, is never formed on the side of the east; it commonly comes from the west, and descends generally from a height situated between two valleys.

We may add further to the phenomena that characterise the fall of hail, a particular noise that precedes it, which is neither that of wind nor that of thunder, but which is a whizzing, similar to what would result either from the knocking of hailstones one against the other, or from the emission of a powerful charge of electricity under the form of a brush.* This noise, added to the heaping up of the clouds, and to the presence, among these accumulated clouds of a deep colour, of certain whitish clouds, are the infallible precursors of the fall of hail, the whole necessarily accompanied by lightnings and thunder; for storms of hail are characterised by the habitual meeting of all the ordinary elements of storms, independently of those which we have just been pointing out, and which are peculiar to them. We may remark, however, that the thunder, which has been heard before the noise of which we have been speaking, is lessened, and even ceases most commonly when this noise commences, which would seem fairly to prove that the whizzing is due to the emission of electricity.

After having analysed, as we have just been doing, all the circumstances that precede and that accompany the fall of hail, and having even indicated some of the conditions essen-

* This noise has been compared to that of a flock of sheep galloping upon a rocky land.

tial to the production of this meteorological phenomenon, let us endeavour to search for its cause, either that which determines its formation, or that which influences the direction that it follows in its fall.

The first theory that is a little satisfactory which has been proposed, is that of Volta; the illustrious philosopher explains the production of the cold necessary for the formation of the nucleus of the hailstone, by the evaporation of water at the upper surface of a very dense cloud, — an evaporation favoured by the dryness of the air of the upper regions of the atmosphere, by the electric state of the cloud, and by the solar rays that strike the surface of the cloud. But excepting the influence of the former cause, which of itself alone is far from being sufficient to explain the cold produced, that of the other two is very doubtful. In particular, how are we to conceive, as Bellani was the first to remark, that the solar rays, by producing a more rapid evaporation, increase the reduction of temperature? for, if they favour evaporation, it is because they heat the water; it is necessary, in order to its producing cold, that the evaporation should be brought about by other causes than by heat. Then, if the action of the solar rays is necessary for the formation of the hailstone, how are we to explain the hails that fall at night, or in the early morning? When once the nuclei of the hailstones are formed, Volta supposes that two clouds, charged with contrary electricity, are arranged one above the other, and that the hailstones, very cold, but still very small, fall upon the lower cloud, into which they penetrate to a certain depth; they become covered with a layer of ice, then, being electrised by the electricity itself of the cloud, are repelled by it, and attracted at the same time by the upper cloud; then mounting up against their proper gravity, they arrive at the upper cloud, where they experience two analogous effects; falling down again afresh into the lower cloud, they are repelled anew into the upper, thus performing *shuttle-cock* a great number of times, as in the experiment of the pith balls, which assume a rapid up and down motion between two discs of metal endowed

with contrary electricities. The hailstones becoming too large, and the clouds losing their electricity, the cause that maintains the hail suspended in the midst of the clouds is insufficient, and we see the latter fall instantaneously almost in a mass. But how are we to admit that two bodies, having also but little density, as two clouds, are able to serve as supports to oscillating balls so heavy as hailstones, especially when it is once known that the electric dance of the pith balls can no longer take place, when a bed of water is substituted for the lower disc of metal? How could it be that the electric power of a cloud might be capable of raising up masses of ice, sometimes weighing nearly as much as one pound? Would it not be much more natural to suppose, in this case, that the two clouds would be carried towards each other, or that an electric discharge would take place between them? Besides, the hypothetic oscillatory movement of Volta has never been perceived by observers, who have been situated in the midst of hail-clouds.

M. Peltier conceives that the electric influence which, according to him, considerably favours evaporation, is sufficient to explain the cold necessary to the formation of hail, he admits that, when two clouds, charged with different electricity, are in presence, and are held at a distance by their specific lightness, an electric radiation is established between them,'— a radiation or transmission of electricity, which, not being able to operate without transport of matter, draws along the molecules of water, by causing them to pass again into the state of vapour. This fresh evaporation, produced by the powerful electric action of the two clouds in presence, takes from the water of the surface of each cloud the heat, that maintains it in the liquid state, so that the portions of the two clouds facing each other, are converted into snowy flakes, which are covered by the shuttle-cock motion with coats of water, of which one part, in evaporating, by the effect of the electricity that comes out of it, causes the portion that remains to congeal. As we see, M. Peltier's theory approaches very closely to that of Volta, except as far as concerns the cause of the cold, which, according to M.

Peltier, resides only in the evaporation produced by the emission of electricity; but, notwithstanding some experiments, which show, in fact, that a liquid evaporates more rapidly when it radiates electricity, and that even its temperature falls, it seems to us impossible to explain, by this cause, which is more mechanical than physical, the enormous lowering of temperature which is necessary for the congelation of the water that forms hailstones.

Let us now endeavour to explain, without having recourse to hypotheses of the class of those of Volta and Peltier, the formation of hail. Let us first remark that, from the very morning of days of hail, the sky presents a peculiar aspect; the blue is not so deep as it is during a day perfectly serene; and we remark in it filamentous *cirrus* more or less developed, which indicates the presence, in the high part of the atmosphere of small icy particles; a presence confirmed by the frequent appearance of coronæ and parhelia. This diminution of transparency in the atmosphere explains the oppressive heat which generally precedes the fall of hail, the radiant heat of the earth being reflected towards the ground, instead of gaining the upper regions of the atmosphere, which, consequently, are by this only colder. The ground, under the influence of these circumstances, is powerfully heated, as well as the strata of air that are in contact with it; but this temperature decreases rapidly with the height, because the strata of air do not mix: and even when a burning heat reigns below, at from 5000 to 10,000 feet, the thermometer is below 32°. There is then produced a very energetic ascending current; and even though the air might not be very moist, yet the upper strata of the atmosphere are rapidly saturated: clouds are formed lower down than the *cirrus*, which must not be confounded with these, and which are *cumulus*. We see the upper stratum of *cirrus* become more dense at the same time that the *cumulus* increase with extraordinary rapidity; the wind, which blows in opposite directions, greatly contributes to this double effect. The clouds are sometimes dissipated without being resolved into rain or hail; but more frequently, on the contrary, they continue to increase by the effect of

currents of cold air, which, in descending, bring about precipitations of aqueous vapour, accompanied by a great liberation of electricity. We thus see how two strata of superposed but distinct clouds are formed, — a condition indispensable, according to all philosophers, to the formation of hail. The most elevated stratum, formed of *cirrus* accumulated by the winds, must necessarily be always charged with positive electricity; whilst the lower stratum, arising essentially from vapours that ascend from the surface of the ground, must be in general negative.* The frozen particles, or flakes of snow, of the stratum of *cirrus*, driven strongly against each other under the impulse of the winds, either the upper or the lower winds, which drive them in all directions, forming whirlwinds, acquire the form of grains of sleet. These grains, driven by their weight and attracted towards the lower clouds, or the *cumulus*, find there a prodigious quantity of water suspended in space; they condense it at their surface, in traversing this stratum, which is always very thick; and if the temperature of the upper regions is still sufficiently elevated, they melt during their fall, and give rise to those large drops of rain which frequently precede storms, and which fall by little showers, like hail; it is only melted hail. We see, indeed, very frequently, sleet or snow fall upon high mountains, whilst at their foot rain falls, which is evidently nothing more than this snow or sleet melted. But, if the grains of sleet are very cold and a little voluminous; if, at the same time, the temperature of the clouds, which they traverse, is sufficiently low (and it is the more so as, these clouds being thicker, the temperature is more elevated near the ground), then the water, which is condensed around their surface, being very cold, is found to be at a temperature which may easily be below 32°. We may, in fact, remark, that the water in the clouds is already in the liquid state; that it has not, therefore, any heat of vaporisation to lose, as if it were in a state of vapour. This water, although be-

* This principle, established by the observations of M. Peltier, is a consequence, as we shall see in the following paragraph, of the mode of production of atmospheric electricity.

low 32°, does not always immediately freeze; for we know that water is able to cool down to 18° and even 36° below 32° without becoming solid, but the least mechanical action is sufficient to bring about its congelation: thus, other grains of sleet that penetrate into it, the electricity that radiates from it, may easily, in producing a shaking in the envelope of water, that surrounds the grains of sleet, solidify it suddenly. This is, probably, what takes place in the hailstones which we find formed entirely of one piece, and containing snowy particles besides the central nucleus; in the case in which there exist concentric particles, it is probable that the water is congealed in proportion as it was condensed. The negative electricity of the lower cloud, in exciting the radiation of the positive of the very cold water, condensed around the nucleus, is one of the most active causes of its congelation, which is accompanied by a particular whizzing that is remarked in hail-storms, and which arises from the emission of electricity. We have a proof of the faculty that water possesses of remaining in a liquid state, even at a temperature very much lower than 32°, when it is suspended in the atmosphere, in the fact, observed by M. Boisgiraud, of large drops of rain, which, in falling upon a soil whose temperature was notably above 32°, were immediately changed into ice by the effect of their contact with a solid body. The same drops of rain ought to have formed hail if, by an exceptional circumstance, they had not been placed beyond the ordinary conditions which bring about this formation.*

M. Lecoq, who was present in the Puy-de-Dôme during the formation of a hail-storm, has minutely described its details, which are perfectly in accordance with the theory that we have been giving. Thus, he has proved the presence of two strata of superposed clouds, and that of two opposed winds driving the clouds one towards the other; he has distinctly remarked that the hailstones do not go from one cloud to the other; they are, on the contrary, animated with a

* It is probable that, in this case, the water condensed around the central grain of sleet belonged to a negative cloud, and that, finding itself in a negative atmosphere, it had not radiated its electricity.

very great horizontal velocity, being driven by a very cold wind; they do not at all strike against each other during their horizontal transport, so that the noise, which precedes their fall, cannot be attributed to their striking; they likewise possess a very rapid motion of rotation; finally, they are seen to repel each other powerfully, and to preserve that whirling, that is perceived from the surface of the earth, and which drives the hailstones in all directions, which the wind finally collects, by impressing upon them its own direction. All these circumstances are perfectly explained by admitting that the electricity that the water contained, which, in condensing, forms sleet, comes out of it in part by bringing about its congelation, and imparting to it a motion of rotation; whilst another part of the electricity remains in the hailstone, which renders it electrical.

In order to explain the causes which lead to the fall of hail taking place in certain localities rather than in others, it would be necessary to analyse all the variable circumstances from one spot to another, which bring about either ascending or descending currents of air, or winds having a particular direction. There are even formed in certain valleys by the effect of the heating of the lateral faces of the mountains, struck by the solar rays, puffs of cold air, which frequently bring with them clouds charged with a sleet, which, in traversing the thick clouds that separate it from the ground, are converted into hail or into thick rain, if the temperature is not sufficiently low. M. Blanchet affirms that things take place in this way in the valley of Leman; and he supports his assertion upon the observations that he has made of the currents of air and of the winds, that reign a little before and during the fall of hail. It is possible that, independently of the direction of the winds, the nature of the soil may influence the fall of hail, as it does the presence of storms; if, indeed, the ground is found, by any cause whatever, to be charged with an electricity contrary to that of the clouds, it will attract these clouds, and, consequently, with them, the rain or the hail which they contain. It is, therefore, only by consecutive and well-made observations in places which

are most frequently visited by hail, that we shall be enabled to decide better, not upon the origin merely of the meteor, which now appears to us tolerably clear, but upon the causes which bring it about, and which circumscribe its fall.

The part that electricity plays in the appearance of hail, had given rise to a belief that we can shelter ourselves from this scourge as one shelters oneself from a thunder stroke—by withdrawing the electricity from the storm-clouds.

Hence the invention of paragrêles: the trials that have been made of them in different countries, particularly in those of Vignoble, have not succeeded. It is true, that the means employed were very imperfect; but the principle does not seem to us sufficiently proved, but that with more perfect means there might have been greater success. In fact, if electricity plays a part in the production of hail, it is but a very secondary part, and it is much more an effect that accompanies this production than a cause which determines it. Likewise, to hinder the formation of hail, if it were true that it is due to electricity, one must reach the cloud itself, where this formation takes place, in order to withdraw from it the electricity; and the most elevated lightning conductors would not reach this. M. Arago, also, had proposed, in order to solve the question, to send up into the storm-clouds, and much higher than Romas made his kite ascend, some captive balloons, furnished with a metallic point serving as a conductor. In thus drawing off their electricity from these storm-clouds, M. Arago is disposed to believe that they are converted into inoffensive clouds, and that thus one can avert the most violent storms. The question is really to know what influence electricity exercises on the meeting of clouds opposed to one another, and the mixture of which is necessary for the production of hail. Is this meeting only the result of the action of two opposed winds, as Mr. Olmsted thinks, or has electricity a part in it? Finally, the meeting of clouds having taken place, does electricity contribute to the conversion of the grains of sleet into hailstones? Can we think that, if electricity were got rid of, we should have

nothing but sleet, and no more hailstones? It would be of great importance definitively to solve these questions, not only on a scientific account, but to the interest of humanity, and particularly of agriculture.

Waterspouts, again, are one of those natural phenomena, like hail, in which electricity seems to play a sufficiently important part, and the nature of which, notwithstanding, is not well determined. Waterspouts are masses of vesicular vapours, that is to say, water mixed with air, as clouds are, but very thick and very dense, which are generally animated by a rapid movement of rotation and translation, having, for the most part of the time, the form of a cone, the base of which is most frequently directed towards the clouds, and the summit towards the earth, sometimes also in the reverse direction. These meteors uproot trees, deprive them of their leaves, blast them, drag them out of the ground, and transport them to great distances; they throw down houses, unroof them, and destroy or break all that they find in their way; often they disperse themselves in rain and hail; they are also often accompanied by balls of fire, shoot forth lightnings, make a noise as of thunder, and generally disperse themselves afterwards. Waterspouts are as frequently observed on the sea as on land.

M. Kaemtz considers that waterspouts are simply due to currents of air; they are vortices of wind, that only take place on a grander scale than those which are often seen on the approach of storms, and which are seen to carry away to a great height light bodies, such as dust, leaves of trees, and straw. In waterspouts, properly so called, the whirlwind does not exist only in the clouds, but also in the water, which rises and rejoins the cloud, which lowers itself towards it; in fact, in the waterspouts which take place either on lakes or on the sea, the water of the lake or sea is observed to rise and meet the cloud, and with it to form two cones, with their summits touching one another, and animated by a very rapid gyratory movement. As we have remarked, waterspouts take place on the sea as well as on land; in the middle of the equatorial sea, they are found only where the trade winds

do not blow in a regular manner; they are more frequently seen in calm regions; they form themselves more frequently at the time of the change of the monsoon; and, in the higher latitudes, they coincide with the storms.

It results from the observations of M. Kaemtz, and from those of several other meteorologists, that waterspouts take place almost always when two opposite winds pass one beside the other; or rather, when a very high wind reigns in the upper part of the atmosphere, whilst the lower is calm. In proportion as the whirlwind, which is formed by the meeting of currents of air, augments, it descends, and if it reaches the surface of the water, this is agitated and rises; at the same time the cloud lowers, and both end by becoming united. But, in general, the waterspout is mostly formed by condensed vapours; and what proves it is, that when it takes place on the sea, the water that escapes from it is never salt. When the air is very dry, waterspouts do not always determine the condensation of vapours, and the violence of wind is only more remarkable.

Thus in this theory, the wind and the currents of air would be the real cause of the formation of waterspouts; and the electric accidents that accompany them would frequently be the natural consequence of the presence of the electricity accumulated in the condensed vapours.

According to other philosophers, electricity would, on the contrary, be the immediate cause of waterspouts. Peltier, in a long and interesting work, has sought to establish an electric theory of waterspouts, either by reproducing on a small scale, by means of artificial electricity, effects analogous to those of waterspouts, or else in searching into the phenomena that the waterspouts themselves present, of which he describes 137, concerning which he has succeeded in obtaining detailed accounts.

He is induced to assume that, when the tension of the clouds is very great, the powerful attraction that results from it lowers these clouds towards the earth, and puts them in communication with it by the portion of cloud that is the most forward. This portion, prolonged as far as the ground,

serves then as a conductor, and offers a way to the escape of electricity from the clouds; it is this descending portion which constitutes the *waterspout.* All bodies placed on the surface of the earth, beneath the cloud from which the waterspout comes, serve as conductors, by reason of their own conductibility, of their form, of their extension, and of their proximity to the ground. The bodies charged with contrary electricity are attracted and raised towards the waterspout, if their weight does not oppose itself; then their electricity being partly neutralised, gravity preponderates, they fall again to the earth, where they again take their former electric tension; they remount anew towards the cloud, thus forming beneath the cone a cloudy mass. If the bodies are attached to the earth, as trees, for example, they instantly become charged with an immense quantity of electricity, they are uprooted, and transported to a great distance by the attraction of the cloud. What seems to confirm this explanation is, that when we observe trees thus uprooted, they are almost all found split into laths of very small section, and of several yards in length; and the portions of wood thus divided seem entirely deprived of sap; an effect analogous to that produced, as we have seen, by the passage of lightning in trees. And, what is more, all the trees which are in the way of the waterspout are not equally thrown down; a choice, so to speak, is made among them,—an effect difficult to explain, if it is the force of the wind, which is the cause of the uprooting; but which is better understood, if it be the result of electric attraction; the difference in the nature, in the interior humidity of the tree, as also in the state of the ground on which it rests, necessarily entering into its susceptibility of being electrised. M. Peltier justly remarks, that the fall of trees is due to a dynamic effect, since it is a consequence of the vaporisation of the sap, produced by the heat, which accompanies the discharge; these dynamic effects which take place in waterspouts, as well as the static effects, show themselves when the clouds are brought down so as to form a good conductor, and when this conductor is put in communi-

cation, for instance, with the trees. But in general the waterspout constitutes but an imperfect conductor between the storm-clouds and the earth, and the noise which accompanies the meteor would be the result of a multitude of small partial discharges, the intensity of which varies with the resistance of the medium in which they occur. As to squalls of wind, which come and unite their material power to that of electricity, they are an immediate production, according to M. Peltier, of electric attractions and repulsions. In fact, when, by a sudden attraction, masses of air are rapidly drawn from the circumference to the centre, their progress is very often resolved into a gyratory movement, which renders their power more destructive. But whatever their energy may be, their action is confined within certain limits, which sufficiently indicates that this disturbing power is entirely local, and that it neither receives nor drives afar the violent winds which accompany it.

M. Peltier has succeeded in reproducing all the effects of waterspouts, in supposing that the cloud is represented by a globe constantly electrified, and covered with points, and putting within its sphere of activity vapours, dust, and water; with water the depression of the liquid takes place; with dust we have currents directed from the centre to the circumference, transforming themselves into gyratory movements. All these effects disappear in replacing the globe furnished with points by a polished globe: instead of the depression of the liquid, we obtain a protuberance; the attraction becoming more considerable, the water rises in a mass, and there is an acceleration of evaporation; with light bodies placed between a plate of copper, communicating with the ground and an upper electrified sphere, we produce the effects of waterspouts.

Without contesting that electricity plays no part in the phenomena of waterspouts, we do not think that the theory of M. Peltier is free from all objection; we recognise, with him, that the theory, which sees only in the action of the winds the cause of these phenomena, is insufficient; since, in 37 waterspouts noticed by him, there were thirty-three

which existed in a calm more or less complete; on the other side, there were ten which took place under a cloudless sky. Since, if we can explain by the electric attraction of a cloud, whirls of dust and small bodies, it is very difficult to believe that this attraction is capable of uprooting trees, lifting up houses; would it not be more natural to admit that it is the cloud that should come near the bodies, which are so firmly fixed to the earth as are trees and houses, than to suppose it is these bodies which go towards the cloud?—could water itself be raised so high as to meet a cloud, as it is in some instances? No doubt, as we have already said, that there are very decided electrical phenomena in waterspouts; we are even disposed to admit that this electricity is more than an effect; but we do not think that we have, as yet, succeeded well in establishing the positive part that it plays in them. Let us again remark, that nothing explains why this electric influence of a cloud on the earth, which ordinarily manifests itself by the fall of lightning, and of the concomitant phenomena, is found translated in some instances into a waterspout. There is there some particular condition necessary for the action to assume this form, which escapes the observer. Might not this condition be a particular state that the globe might possess in the portions situated a little below the surface of the ground on which the waterspout moves? Certain subterranean phenomena, which frequently precede or accompany storms, and of which we will speak in the following section, would seem to give some consistence to this opinion; the waterspout would thus at once be both a terrestrial and atmospheric phenomenon.

It is again to the electric action exercised by the clouds, that M. Peltier attributes the phenomena known by the name of *raz de marées*, and of *seiche*. The raz de marée consists in a sudden and sometimes very considerable elevation of the level of the sea, quite independent of the tides properly so called, that can only be observed close to the coasts. Thus, on the 17th July, 1841, at Cette, the level of the sea was seen to rise in a few minutes to four feet above its ordinary level; other examples are mentioned in different seas. According to

M. Peltier, this phenomenon is owing to the powerful attraction of an electric cloud, which, acting on a surface of water, sometimes confines itself to raising vesicular vapour under the form of columns; then, when it is more powerful, it raises the water itself also under the form of boiling columns; and even in some cases it raises the whole surface of the water throughout a great extent, in the rarer case in which this attractive power is almost equal upon the whole extent of the cloud. The seiches are a phenomenon of the same kind, which are observed upon the lakes, and especially upon the Lake of Geneva. They consist in the changes of level that are suddenly manifested, without there being anything that can cause them to be anticipated, and which only take place at the narrow extremities of the lake. These changes, which are sometimes considerable, for they have been seen to rise to about two yards, last but an instant; but they are accompanied by tolerably prolonged oscillations in the level. They can be attributed neither to gusts of wind, nor to variations in the atmospheric pressure, for they are generally accompanied neither by a stronger wind than usual, nor by movements in the barometer. It is, then, as Bertrand was the first to conceive, by electric clouds, which attract and raise the waters, that they may be explained; these waters, falling back immediately, produce undulations, the effect of which is, like that of the tides, the more sensible in proportion as the banks are more contracted. A fact, favourable to this explanation, is that the time which the water takes to rise above its level is less, in proportion as it rises higher; and that, on the other hand, it requires more time to fall, in proportion as it rose higher.

Thus, according to Peltier, waterspouts, raz de marées, and seiches, would be only modifications of a same phenomenon: it is to the same cause that must be attributed the entire disappearance of the water of ponds of little depth, which, being raised up with what they contain, give rise to those showers of solid substances, sometimes even living ones, such as frogs and fishes, which are noticed from time to time.

As we have just seen, the part played by electricity in the greater portion of meteorological phenomena is very important, even while it is not yet well defined. It is probable that this part is even more general than we could conclude from the observations that we have related; what would seem to lead us to a presumption of this is the relation that exists between the variations of the barometer and those of the electric state of the air; now, the variations of the barometer are connected with all the meteorological variations of the atmosphere: for they are attributed either to the influence of the winds, or to the modifications of temperature, or else to the changes that supervene in the quantity of the vapour diffused in the air. Whatever may be its cause, it no less follows, from very consecutive observations made by M. Quetelet, that the barometer is retained higher in proportion as the air is more positively electrised; the difference, which is particularly sensible during the cold months, diminishes in summer; and it changes in sign during the hottest months. When the electricity of the air is negative, the barometer, all things being equal, attains its lowest state.* Besides, this case is very rare; for it has only presented itself twenty-three times in the numerous observations of several years, by means of which M. Quetelet has drawn out the following Table, proceeding as follows. He formed for each month two groups of his electric observations, one containing the observations that surpassed the mean indication of the month, the other containing the observations, on the contrary, that fell below the mean; then he afterwards took the barometric heights that corresponded to each of his electric observations, and which are in this manner

* M. Peltier, in a large work upon the cause of barometric variations, attributes them exclusively to the electric state of the vapours. Setting out from the principle that these vapours are composed of vesicles which, having each their own electricity, are mutually repelled, he shows that when they are positive their density increases, because the negative globe in attracting them brings them each toward the other; whilst, when they are negative, the repulsion, exercised upon them by the globe, separates them, and consequently diminishes their density, that is to say, the quantity of them that are found in the same volume of air. In the former case the pressure should increase, in the latter it should diminish, in conformity with observation. M. Peltier endeavours, by his theory, to account for the differences that are presented with the latitudes, climates, and seasons, by the variations, whether regular or irregular, of the barometer.

found to be distributed naturally into two groups. He had thus for each month a barometric mean corresponding to the days in which electricity was manifested with the greatest intensity, and a second mean for the days in which there had been proved to be the least electricity. M. Quetelet has not allowed to enter into this calculation the twenty-three observations for which the electricity was negative; these observations have been considered apart; the mean of these twenty-three observations has given for the barometric height 29·52 in., a value which differs considerably from 29·7 in., which is the mean deduced from the last seventeen years. The following now is the Table, drawn out according to the observations for which the electricity was positive, and from which M. Quetelet has deduced the conclusions that we have just mentioned:—

Months.	Barometric state, when the Electricity was		Difference of the preceding numbers.	Degrees of Electricity for a Sky		Relations of these Numbers.	Relative Intensity of the Wind.		Relations of the two preceding Numbers.
	Above the Mean.	Below the Mean.		Serene.	Cloudy.		Diurnal Max.	Diurnal Min.	
January -	29·81 in.	29·66 in.	0·15 in.	1133°	268°	4·23	339	206	1·27
February -	29·75	29·73	0·02	493	220	2·24	288	180	1·60
March - -	29·78	29·55	0·23	261	129	2·01	422	231	1·83
April - -	29·57	29·52	0·05	149	71	2·09	314	126	2·50
May - -	29·71	29·69	0·02	63	46	1·39	360	148	2·43
June - -	29·72	29·70	0·02	37	36	1·03	323	113	2·88
July - -	29·75	29·76	0·01	35	41	0·85	328	141	2·32
August -	29·68	29·64	0·04	64	56	1·14	338	149	2·27
September -	29·76	29·73	0·03	78	42	1·86	282	98	2·88
October -	29·72	29·55	0·17	168	75	2·24	400	229	1·74
November -	29·75	29·66	0·09	226	109	2·04	379	270	1·40
December -	29·75	29·69	0·06	571	181	3·15	327	226	1·44
Mean -	29·73	29·65	0·08	273	106	2·56	4051	2258	1·79

Origin of Atmospheric Electricity.

Volta and De Saussure had thought they were able to attribute atmospheric electricity to the evaporation that takes place upon the surface of the globe. De Saussure, in particular, had shown, by a great number of experiments, that whenever water, pure or more or less salt, acid, or alkaline, is projected upon a metal crucible, heated to redness, the evapora-

tion that takes place is accompanied by a strong liberation of electricity. But we have shown that this liberation is not due to evaporation, but rather to a chemical action. M. Pouillet has shown that, if the crucible is of platinum, and the projected liquid distilled water, there is no electricity produced.* It is no longer the same, according to him, if the water is salt; in this case there is a chemical disaggregation, even with the platinum crucible, and there is a liberation of electricity. Now, as the immense proportion of water that is evaporated at the surface of the earth is the water of the seas, which is salt, M. Pouillet is disposed to see, in this evaporation of sea-water, the source of atmospheric electricity. He adds to it, as a second source, the vegetation that takes place upon the solid part of the surface of the globe, which, according to him, furnishes positive electricity to the air, whilst it gives negative to the ground. But, we have seen that the liberation of electricity in the act of vegetation is more or less questionable, and in any case is very feeble and very insufficient to account for the considerable electric charge of the atmosphere. With regard to the evaporation of the sea-water, it would appear, according to some experiments of M. Reiss's, that it is to the friction of the drops of water drawn along with the vapour, against the sides of the platinum vessel, in which the evaporation is brought about, rather than to the evaporation itself, that the liberation of electricity would be due, which would thus not result from chemical segregation.

It seems therefore necessary to recur to more general causes, in order to find the origin of atmospheric electricity. The idea had been entertained, of seeking for it in the calorific action of the sun upon the atmosphere, and in the distribution of temperature, which is the consequence of this; but hitherto experiment has never been able to demonstrate in gases and vapours the slightest trace of thermo-electricity. This negative result is a necessary consequence of the theory of thermo-electric phenomena, such as it comes

* Vol. II. p. 713.

out from the labours of Magnus; besides, liquids themselves not being susceptible of becoming electric by heat, vapours and gases must be still less so.

It is also in the action of the solar rays that M. Schoenbein wishes to find the cause of atmospheric electricity; but it is in their chemical, and not in their calorific action. After having proved that, under the influence of light, oxygen is susceptible of exercising a chemical action, as if it were ozonised, M. Schoenbein considers that the oxygen of the air, under the influence of the solar rays, becomes capable of acting electro-chemically upon the molecules of water. There results from this an electric polarisation of the filaments of the particles of water, of which the clouds are composed, and consequently an electric tension. But this theory would require, in order to be justified, to rest upon direct and positive experiments; and besides, it would only account for the electric manifestations of storm clouds, and not for those of the atmospheric air in the normal state.

M. Becquerel, sen., as the result of researches upon the liberation of electricity, which takes place at the contact of the ground and a bed or stream of water, — a liberation which he has succeeded in rendering very sensible *, — has asked, if we could not find, in this production of electricity, the origin of that which charges the atmosphere. When the water evaporates, either from a stream of water or from the ground, it must necessarily carry with it an excess of electricity of a similar nature to that possessed by the surface from which it evaporates, which is diffused in the atmosphere. This electricity may arise, not only from the reaction of the water of the river upon that which surmounts the

* The apparatus employed in the researches of M. Becquerel are composed, 1st, of porous diaphragms of porcelain or small bags of sail-cloth, each containing a plate of gold or of depolarised platinum, surrounded by the carbon of sugar-candy, in order to render the electric effects constant, for some instants, for measuring them; 2nd, of sine-compasses of a tolerably great sensitiveness, appropriated to experiments of this kind; 3rd, of atmospheric electrometers, intended for collecting the electricity of the vapours forming above the water on the ground; 4th, of various accessories, such as resistance-bobbins, conducting-wires, covered with gutta-percha, &c. As may readily be conceived, it is the porous vessels that are placed in the water and in the ground.

ground, but also from the decomposition of organic matters; in this latter case, the vapour is always positive, whether it arises from the river or from the ground, in which the decomposition is brought about; in the former case, the two vapours are of contrary signs; the effects are then complex.

There is in M. Becquerel's theory one point, which appears to us perfectly plausible; it is, that the vapour of water is the vehicle which carries into the atmosphere the electricity with which the liquid from which it emanates is charged. But the cause to which he attributes the production itself of the electricity does not appear to us either sufficiently general or sufficiently constant, either in intensity or in the nature of its manifestations, to be able to be considered as the veritable and only source of atmospheric electricity.

We consider, therefore, that we must seek for this source in some natural action of an order superior to those that we have pointed out. We can find an action of this kind only in the influence of the sun upon the earth, or in the earth itself. We have excluded the chemical action of the sun; with regard to its direct action, it might perhaps give rise to closed currents, constituting magnetism; but we do not see how it could develope upon our globe static electricity, and in particular charge at the same time the earth itself with negative electricity, and its atmosphere with positive electricity. It is, therefore, in some great natural phenomenon, operating at the surface, or near to the surface, of the terrestrial globe, that it seems to us the origin of atmospheric electricity ought to be found; and this phenomenon appears to us to be the continuous chemical action that takes place upon the interior surface of the solid crust of the globe, where the limit exists between the portion already solidified, and that which is still in the state of incandescent liquidity. This chemical action evidently arises, not only from local actions*, but also from infiltrations of the water of the sea; and it must follow from this, according to the known laws of the

* Might not the electricity generated by these local actions be connected with earthquakes? The subterranean noises, very similar to rolling of thunder, which generally precede, and frequently accompany violent earthquakes, would seem to give a presumption of this.

liberation of electricity in chemical actions, that this water is charged with positive electricity, whilst the solid part of the earth is charged with negative electricity. The vapours that rise from the sea would therefore constantly carry away with them into the atmosphere positive electricity, whilst the globe would retain, in the part where there is no sea, negative electricity. But it is especially in the tropical regions, in which the evaporation is much more active, that the atmosphere would receive from the sea those positive vapours, which, after being raised more or less vertically, would be driven into the two hemispheres by the tropical current of the high regions of the atmosphere. Travelling first horizontally, this current of air, charged with positive vapours, would always approach more towards the surface of the ground, in proportion as it became cooler in receding from the equatorial regions; and, at the poles themselves of the earth, or in their neighbourhood, it would come almost into contact with the negative ground, thus producing, as we shall see in the following Chapter, the phenomenon of polar auroræ. We conceive likewise, in this theory, that the atmosphere must contain much more of positive vapour in the hemisphere in which the sun is situated, than in the hemisphere in which it no longer is, since the evaporation there is much more powerful; that hence it is between the vernal and the autumnal equinox that the greatest number of storms must take place in the northern hemisphere, whilst it must be the reverse in the southern; with regard to the equatorial regions, it must take place there all the year equally. On the other hand, the vapours must become much more lowered in the northern hemisphere than in the southern between the autumnal and the vernal equinoxes, and reciprocally for the southern hemisphere; thus, no longer giving rise to storms, at least very rarely, but essentially to fogs, always positive, which cover then in great part the surface of the earth. Beside these positive vapours, which constantly rise from the sea, and which give to the atmosphere its positive electricity, there comes out from the solid earth itself, or rather from the water that it contains here

and there, and which is in contact with it, negative vapours, which, especially in summer, when the evaporation is more active, neutralise in part, on rising into the atmosphere, its positive electricity, at least in the region nearest to the earth. It is from these negative vapours, that rise from the ground, that the lower negative clouds are derived, whose presence contributes essentially to the storms of summer, and in particular to the production of hail; when very thick and very dense, they attract the positive clouds of the high regions of the atmosphere, filled with icy particles, which become the nuclei of hailstones, or those of large drops of rain, if the temperature is not sufficiently low. It is true that, in order that these phenomena may be manifested in all their intensity, it is necessary that the local winds, which are due especially to the calorific action of the solar rays upon a soil cut up in a thousand ways, should accumulate the lower clouds in a same portion of the atmosphere, which likewise brings about, by the attraction which they exert upon the upper positive clouds, the accumulation of these latter in the same regions. The absence of these negative clouds, which arise from the ground in regions of the atmosphere, situated above the open sea, at great distances from the coasts, explains the rarity of storms in these latitudes, which we have proved in the Third Section.

Again, let us add that the difference in the nature of the electricity of the vapours which arise out of the sea, and of those less abundant which escape from the ground, accounts in a very satisfactory manner, not only, as we have seen, for storms, but for various electric states of the atmosphere in these different regions, and for the variations which this state undergoes. Thus we rarely find negative electricity in the air during the cold months, when the evaporation proceeding from the soil is nothing, or very weak. Thus again we comprehend why the humidity of the air, in the portion of the atmosphere nearest to the earth, increases the intensity of its electric state in winter, and diminishes it in summer; it is that in winter this humidity proceeds essentially from the vapours, with which the air itself is charged, and which are

positive, whilst in summer it proceeds from vapours which arise from the soil, and which, being negative, neutralise a certain proportion of the naturally positive electricity of the atmosphere. The diurnal monthly epochs of *maxima* and *minima* of electricity are equally a result of the quantity, more or less great, of vapours with which the air is impregnated, and of the proportion of these vapours supplied by the air and by the earth, that is to say, by cooling and by evaporation.

It now remains for us to give proofs in support of our hypothesis on the origin itself of the electricity. We first of all find them in the fact that sea-water is positive, whilst the surface of the earth is negative; this point, established by numerous observations, and in particular by those of M. Pëltier, as far as concerns the land, those quite recent of M. Becquerel, as far as concerns the sea, explains why the air is already positive in that stratum which is in contact with the surface of the sea, whilst in the plains further removed from seas it is only at a certain distance from the ground that it commences to become so. It accounts equally for the attraction exerted by the mountains, necessarily negative, on the low hanging clouds, as well as for the phenomenon designated by the name of mountain smoke. But nothing better shows the difference that exists between the electric state of the terrestrial globe and that possessed by its atmosphere, thanks to the positive vapours which it contains, than the remarkable subterranean phenomena which sometimes take place on the approach of storms. We will borrow from M. Arago, who cites a great number of them, the description of some of these phenomena. In the Vicentin Hills there is a fountain which, even after a long drought, and even at times when it is completely dry, overflows suddenly when a storm is at hand, and fills a wide canal with a very turbulent water, which spreads itself in the neighbouring valleys. There was dug at some distance from Perpignan an artesian well, which furnished at the commencement a great quantity of water gushing out; this water rapidly diminished, which all the inhabitants attri-

buted to the accumulation of matter towards the lower part of the hole. It happened one day, when the sky was overcast with very stormy clouds, that a low rumbling noise was heard underground, very soon followed by an explosion, after which the artesian fountain supplied the same quantity of water as before. In October, 1755 *, a sudden inundation caused immense ravages in most of the valleys of Piedmont; the disaster was preceded by horrible thunders, according to Beccaria, to whom we are indebted for this relation; and according to unanimous consent they had for a principal cause the immense volume of subterranean water, which all of a sudden, during the storm, came out from the heart of the mountain by fresh openings. It has been remarked that, almost all thermal springs suffer, at the approach of storms, a particular agitation, which is manifested by an extraordinary bubbling, or by other symptoms, which show the electric condition of the deep places, whence they arise, and from which they have probably been borrowed.

There exists, therefore, within the solid crust of our globe, which is always essentially negative, some portions which, at times, are more so than others are; and from this, local phenomena result, such as those which we have just been pointing out, such likewise as waterspouts and others, in which the local influence of the ground is evidently manifested. These differences in the negative state of different parts of the earth, whether at its surface or at a certain depth, are a very natural consequence of the differences of conductibility, and of the variations in the internal chemical action, or in respect to the points themselves at which it takes place, or in respect to its intensity.† In as far as concerns this chemical action itself, we have a proof of the enormous quantity of electricity that it produces, in that with which the vapours

* It was the year of the earthquake at Lisbon.

† We conceive, indeed, that the presence of subterranean waters is able to bring about a greater and a more prompt accumulation of electricity in the parts of the ground that are near to them; in like manner we conceive that metallic veins or conducting rocks, that penetrate to great depths, are able to bring about also, in the points to which they correspond, a greater electric charge; of this we have quoted numerous examples.

and the ashes that come out of volcanoes are charged. We have already quoted the electric storm which was so violent, and which accompanied the eruption of Vesuvius, in 1794; very recently, a new volcanic eruption, which has taken place in the Sea of Celebes, has likewise given rise to electric effects, lightnings, thunders, &c., such as those which are generated by an ordinary storm. M. Palmieri has observed that the vapours which arise from the crater of Vesuvius are always charged with a powerful positive electricity; and the famous dry fog of 1783, which for so long a time covered a good portion of Europe, and the positive electricity of which gave rise to frequent storms, had evidently a volcanic origin; for its appearance followed the violent earthquakes that occurred in Calabria, at the commencement of the same year; and it was preceded in the northern regions of Europe by a south or south-east wind. A similar phenomenon had before this been observed in Persia, in 1721, after the great earthquake that destroyed the town of Tauris, in the same year.

When we see that a single volcanic eruption suffices to charge the air with so considerable a quantity of positive electricity, we easily conceive how the sea-water, which is in communication with the subterranean places wherein these eruptions are elaborated *, is constantly positively electrised. There exist very probably a considerable number of submarine volcanoes constantly in a state of activity; the upheavings of certain coasts, the appearance, from time to time, of some of these volcanoes at the surface of the sea, are so many proofs of this. When once the sea-water is positive, the vapours that arise from it are also so; and herein, as we have already said, is the explanation of the positive electricity with which our atmosphere is charged.

We see, therefore, that the theory which we have laid down

* The very abundant presence of chlorides and of hydrochloric vapours in the products of volcanic eruptions, the very great number in proportion of volcanoes near to the sea or submarine, are striking proofs of the action of sea-water upon subterranean incandescent matter; however, a very remarkable fact, observed by M. Saint-Clair Deville, is the absence of vapour of water, and, on the contrary, the abundance of the vapours of chloride of sodium in volcanic emanations.

accounts, in a satisfactory manner, even in their smallest details, for all the phenomena of electric meteorology: we must note that there is but one alone which escapes entirely our comprehension; it is that of ball-lightnings. However, the following is an explanation of this singular meteor, which, with all reserve, we venture to present. Might it not happen that, by the effect of the considerable propagation of electricity that is brought about in the clouds during a storm, the water might be decomposed, as it is whenever there is a propagation of electricity, and that hydrogen, mixed with a portion of atmospheric air, contained in a kind of envelope of water, by a cause that is beyond our apprehension, but of the same nature as that which determines the state of water in the clouds, would determine the formation of these balls, which are, as it were, a species of balloons, that float at a greater or less height in the air? The frightful noise that accompanies their explosion would be due to the combination of the hydrogen and oxygen, that would take place at the moment of the discharge of the two contrary electricities, in the route of which they might be situated; the direction of the route itself which these balls follow would depend, like that of lightning-flashes, upon the numerous circumstances which determine the road that is travelled by the two electricities in their tendency to neutralise each other. With regard to their luminous appearance, which is not accompanied by sensible heat, it would arise from the electric radiation of the aqueous envelope that had come out of the cloud with a strong charge of electricity; a radiation that would be changed into an explosion at the moment when the departure of this electricity would be more actively urged on by the action of the contrary electricity of surrounding bodies.

Without attaching more importance than it merits to the explanation that we have been giving, and which would require, in order to assume consistency, to be based upon well-made observations and direct experiments, I cannot, however, refrain from remarking, that it would not be impossible that the decomposition of water and the presence of hydrogen, which result from it, might play in the phenomena of elec-

tric storms a greater part than is commonly supposed.* Who knows, in particular, whether the noise itself which accompanies the electric explosion, and which constitutes the element of thunder, might not be due to the recomposition of the water, decomposed by the propagation of electricity in the cloud? This decomposition and recomposition might follow each other immediately, without leaving any other trace than the noise arising from the combination of the oxygen and hydrogen. And this is not a vain hypothesis; for we have a direct proof that things may take place thus, in the frightful noise that accompanies the passage of the electric spark in Ruhmkorff's induction apparatus through distilled water, which is at the same time slightly decomposed. Moreover, whether this noise arises from the decomposition and recomposition of water, whether it arises simply from the vibration imparted directly to the water by the passage of the discharge, it none the less furnishes a perfectly plausible explanation of the noise of thunder, with which there is the greatest analogy, except that there is an absolute intensity naturally much less, and that it is not accompanied by a rolling; differences which are a necessary consequence of the very dissimilar circumstances under which it is produced. We may add, in favour of the analogy, that we have just been pointing out, that M. Dumoncel, on causing Ruhmkorff's induction spark to pass through thin strata of water, divided in pools on a varnished surface, saw the track of fire, by which the spark is manifested in traversing the water, terminate by a red ball, similar, save in size, to that which constitutes ball-lightning.

List of the principal works relative to the subjects treated of in this Chapter:—

De Saussure.—Electrometers and atmospheric electricity. *Voyage dans les Alpes*, in 4to. Neufchâtel, 1784, t. ii. pp. 164. and 172.

Peltier.—Atmospheric electrometers. *Ann. de Chim. et de Phys. (New Series)*, t. iv. p. 385.—Electric meteorology. *Arch. de l'Electricité*, t. iv. p. 173.; *Observations and Researches upon the Formation of Trombes*, 1 vol. in 8vo.

* In this might be found the application of M. Schoenbein's considerations on the influence of ozonised oxygen, which exists in great quantity in the air in the time of storms; we easily conceive that this influence might contribute in a notable manner to the decomposition of water.

Paris, 1840; *Notice on the Scientific Labours of Peltier*, 1 vol. in 8vo. Paris, 1847.

Quetelet.—Electricity of the air; relation of humidity with electricity. *Mémoires de l'Académie de Bruxelles*, 1849—1854; *Arch. des Sc. phys.* t. xi. p. 177., t. xxvii. p. 5., t. ii. (1816), p. 93., and t. xlii. (1829), p. 203.

Schubler.—Atmospheric electricity. *Bibl. Univ.* t. ii. p. 93., and t. xlii. p. 203.

Birt.—Observations of atmospheric electricity at Kew. *Arch. des Sc. phys.* t. xii. p. 224.

Plantamour.—Idem. *Arch. de l'Electricité*, t. i. p. 260.

Romershausen.—Apparatus for atmospheric electricity. *Arch. des Sc. phys.* t. x. p. 179.

Palmieri.—Atmospheric electricity. *Arch. des Sc. phys.* t. xxvi. p. 105.

Arago.—Storms, thunder, lightnings, &c. *Notices scientifiques*, t. i. (Œuvres Complètes).

Volta.—Periodic return of storms. *Ann. de Chim. et de Phys.* t. iv. p. 245.

Gay-Lussac.—Formation of storm-clouds. *Ann. de Chim. et de Phys.* t. viii. p. 158.—Instruction on lightning conductors. *Ann. de Chim. et de Phys.* t. xxvi. p. 258.—Formation of fulminary tubes. *Idem.* t. xxxvii. p. 319.

Baër.—Frequency of storms in the polar regions. *Bibl. Univ.* t. xxx. (1840), p. 407.

Pouillet.—Instruction of the Académie des Sciences upon lightning conductors. *Comptes rendus de l'Académie des Sciences de Paris*, t. xxxix. (1854), p. 1142.

Blanchet.—Memoir upon a storm and upon hail. *Annuaire Météorologique de France* (1852).

Despine.—Hail fallen in 1840 in Piedmont and in Savoy. *Académie des Sciences de Turin*, t. vii. (*Second Series*).

Lecoq.—Formation of hail. *Ann. de Chim. et de Phys.* t. lxi. p. 202.; and *Bibl. Univ.* t. iv. (1836), p. 217.

Boisgiraud.—Formation of hail. *Ann. de Chim. et de Phys.* t. lxii, p. 91.

Schoenbein.—Origin of the electricity of clouds. *Idem.* t. xv. p. 89.

Becquerel.—Origin of atmospheric electricity. *Comptes rendus de l'Académie des Sciences de Paris*, t. xlii. (1856), p. 661.

Kirwan.—Positive electricity of the dry fog of 1783. *Bibl. Brit.* t. xxii. p. 235.

Oersted.—Trombes. *Bibl. Univ.* (1840), t. xxiii. p. 145.

Waller.—Microscopic observations upon hail. *Arch. des Sc. phys.* t. iii. p. 30.*

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* The observations of Dr. Waller, which we have omitted to cite, confirm in many points what we have said upon the formation of hail. Thus he has found that hail has a temperature of from 37° to 39°, and that it contains a considerable quantity of air, which it abandons in melting, a proof that it is indeed the water of the clouds that is congealed. He has succeeded in causing the vapour of water to freeze upon a plate of glass under the microscope, in obtaining, when he operated in winter, regular crystals and a few globules, whilst in summer the crystals were less numerous and were confused, and the globules were very abundant. This is exactly what is presented in nature,—a double result, which is explained by the small quantity of the vapour, in the former case, and the slowness of condensation, whilst in the latter the circumstances are precisely the reverse.

CHAP. III.

TERRESTRIAL MAGNETISM.

Description and Theory of the Instruments.

We have already spoken in the first volume* of the property that is possessed by magnets, of assuming a determinate direction, under the influence of the terrestrial globe; we have even described some of the apparatus by means of which we succeed in determining this direction, either in a vertical or in a horizontal plane, that is to say, the inclination compass and that of declination. We are now called on to return to the force itself which produces that direction, and which is designated under the name of *terrestrial magnetism:* it is one of the modes of manifestation of the natural sources of electricity; since magnetism itself is only a particular form of electricity. We shall, in fact, see, by the study that we are about to make of it, that it is indeed from the terrestrial globe that the power emanates which acts upon magnets placed at its surface; and, after having endeavoured to analyse this force in its different elements, we will endeavour to discover its origin.

The magnetic force of our globe is manifested at its surface by three classes of phenomena, namely, the *declination* of the magnetised needle, its *inclination*, and the *intensity* with which the force acts upon the needle. As we have already said, the declination is the angle, that is formed with the direction of the meridian of the place, by the direction of the magnetised needle, placed upon a vertical pivot, or suspended by the aid of a thread, without torsion, in such a manner that it holds itself horizontal. The inclination is

* Vol. I. p. 158.

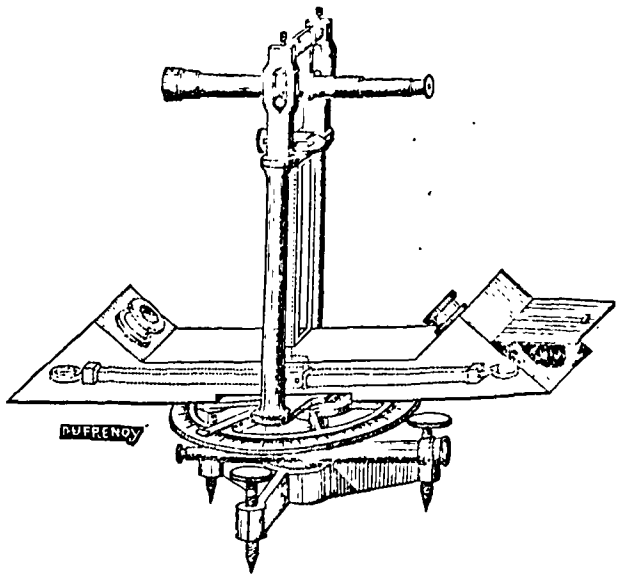
the angle, that is formed with the horizon in the magnetic meridian by the direction of a magnetised needle, sustained by its centre of gravity, around which it is able to turn freely in a vertical plane. These three elements, declination, inclination, and intensity, vary not only from one place to another, but in a same place, with time; they even suffer variations in the interval of the twenty-four hours that constitute the day; very small ones, it is true, but yet appreciable, and subject to a remarkable regularity: they sometimes also manifest irregular and accidental variations, designated under the name of disturbances, and the existence of which is connected with the presence of some natural phenomenon, such, in particular, as that of the aurora borealis.

We understand how important it is for the study of terrestrial magnetism, which is itself so essential a part of terrestrial physics, that we should have apparatus susceptible of giving, with the greatest possible precision, the declination, the inclination, and the intensity, either in an absolute manner in a determined instant and place, or in the variations which they suffer from one place to another, or from one moment to another, in a same place. Among the numerous apparatus that have been contrived with this in view, we shall confine ourselves to describing, first, those of Gambey, which have been long employed at the Observatory of Paris, and which are based upon the same principles as the common instruments, of which we have already spoken in the First Volume, but into which the skilful French artist has introduced many perfections of detail; second, Gauss's apparatus, designated under the name of *magnetometers*, and the employment of which has largely contributed to the progress that has been made for several years in the study of terrestrial magnetism; third, finally, the registering apparatus, which present nothing new at bottom; but which are so constructed that the observations register themselves.

Gambey's declination compass (*fig.* 353.) presents a graduated horizontal circle, which rests on a tripod, with adjust-

ing screws, and is connected with a theodolite, by means of which, by looking at a mark before and after the observation,

Fig. 353.

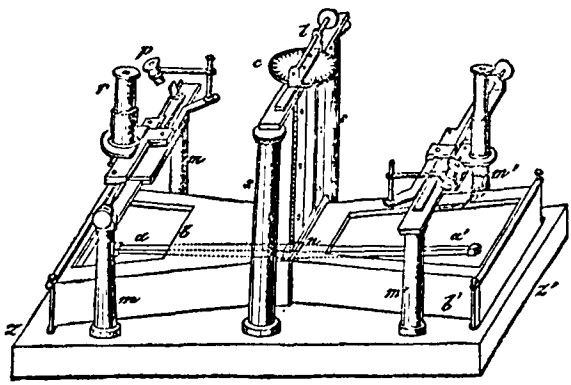


we may satisfy ourselves that the limb has remained fixed. The axis of the circle is pierced, and receives an interior axis, which carries a transom, furnished with verniers, and a plate upon which is fixed all the movable part of the apparatus: this latter is composed of two vertical columns united by a transverse piece, at about half their height, and carrying at their upper extremity a horizontal axis, to which is fixed a telescope. A prismatic magnetised bar, about 1·6 ft. in length, furnished at each of its extremities with a ring, carrying two wires crossing, rests upon a stirrup, to which is attached a thread without torsion, coiled in its upper part upon a small roller, which is supported by the transverse pieces fixed to the columns. A box, which protects the magnetised bar from currents of air, is pierced at each of its extremities by two openings, one enabling us to view the cross of the wires with the telescope, the other intended for illuminating these same wires. Finally, there is no need of adding, that all the parts of the apparatus are of copper; and that the smallest

particle of iron must not be found in them. By means of this instrument the angle is determined that is made by the vertical plane passing through the magnetic axis of the bar in equilibrium, and the meridian plane of the place, or any other vertical plane, whose azimuth is determined. By substituting first for the magnetised bars a perfectly similar prism of copper, we satisfy ourselves, by looking at these cross wires in the microscope, that when the wire is without torsion the vertical plane, passing through the optical axis of the microscope, contains the axis of the bar. The magnet is then replaced in the stirrup, and the whole movable part of the instrument is turned until we see, coinciding with the wire, which in the microscope determines its optical axis, the point of crossing of the wires of the bar, which is motionless, and, consequently, in equilibrio; at this moment, the vertical plane passing through the optical axis, is the plane of the magnetic meridian, if we assume, however, that the magnetic axis of the bar is the same as its axis of form. The same operation repeated, after having turned the magnet round, gives rigorously the magnetic meridian; it now only remains to measure the angle, through which it is necessary to turn the mobile system, in order that this same optical axis shall pass, either through a star or through an object, whose position is known. Now, for this purpose it is necessary that the microscope, still preserving its axis, should be transformed into a telescope; and it is with this view that its object glass is formed of two different parts — the one central, much more convex, forming by itself alone the object glass of the microscope; and the other peripheric, more flattened, forming the object glass of an astronomical telescope. A diaphragm, which covers at pleasure one or other of these two parts, renders the telescope fit for the use that is desired to be made of it. We have not spoken of the precautions that must be taken, in order to render the instrument horizontal, nor of the number of times that it is proper to repeat the observation, in order to render its result as exact as possible; in this respect it is necessary to apply the same rules which regulate the employment of astronomical instruments.

When the object is not merely to observe the absolute declination, but the variations of declination, a slightly different instrument is necessary, of which the following is the description. Two fixed pillars (*fig.* 354.) support a

Fig. 354.



roller, around which is wound the thread that carries the magnetised bar: this bar is terminated at each of its extremities by an ivory plate, upon which is traced a division in hundredths of an inch, symmetrically around its axis. A microscope, movable by means of an endless screw along a scale, upon which is arranged a lens for facilitating the readings, serves to observe the march of each of the extremities of the bar; finally, a box, which contains the magnet, and a glazed frame, which covers the thread, shelter the apparatus from currents of air. In order to make use of this instrument, after having levelled the bar, and brought the interior wires of the microscopes in coincidence with the axis, the variations of the declination are measured, either by counting the divisions of the scale engraved upon the ivory plate which pass under the wire of the microscope, or by turning the endless screw of the microscope, so as to cause its cross wires to rest in coincidence with the axis of the bar, and then reading off how much it has been advanced or receded.

The inclination compass, of which we have already given an

abridged description in our first volume *, consists (*fig.* 355.) of a horizontal circle divided into half-degrees, and giving the minute by means of verniers, upon which is moved a transom, fixed to a solid plate. Upon this plate rise two pillars, which support a double frame and a vertical circle: the exterior frame is fixed, whilst the interior frame is movable around one of its extremities, and serves, by the motion of which it is susceptible, to bring back the centre of the needle into coincidence with the centre of the vertical circle. The axis of the needle passes into two notches, which support it when observations are not being made; and its pivots are made to rest upon small planes of agate or rock crystal.

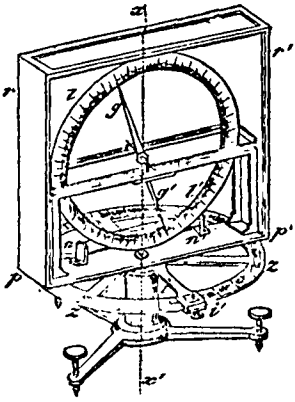


Fig. 355.

Let us now indicate the precautions, that must be taken for the determination of the inclination, an important point upon which we had not treated, when we spoke, in Volume the First, of the inclination compass. We know, that it is a very rare thing to find a needle, whose centre of gravity perfectly coincides with the centre of suspension; whence it follows that the direction which is assumed by the magnet is the resultant of the two forces that are acting upon it, one terrestrial magnetism, and the other gravity; on this account it is that it is necessary to reverse the poles of the needle. But it is necessary to bear in mind that the mean of the values found for the inclination before and after the interchanging of the poles, would give the true inclination only so long as the distribution of the magnetic force in the needle is perfectly symmetrical, and is not altered by the inversion of the poles: now this does not always take place, especially when the needle that is employed is new; so that it would be more prudent, before

* Vol. I. p. 161. *fig.* 74.

returning the needle to experiment, to make it oscillate, so as to be sure that its magnetic force has remained the same. A second cause of error is the non-coincidence of the magnetic axis with the axis of the form of the needle; this is taken into account by turning the needle over on its pivots before and after the reversion of the poles, so that an observation of inclination requires, according to this method, four measures of angles. But, in order that the mean of these four observations may be exact, it is necessary to assume that the diameter of the divided circle, which passes through the division 90°, is vertical; if it were otherwise, the angle comprised between the vertical and this diameter, would give an error upon the result observed: it is important to eliminate this error, and the surest means of arriving at this, is each time to effect the turning of the entire instrument, which should be movable around a vertical axis, and furnished with levels, in order to make sure that this axis remains vertical during the turning. The complete observation of the inclination is thus composed of eight observations instead of four.

The intensity is the particular element of terrestrial magnetism, the determination of which presents the greatest difficulties. In fact, the value of the directive force that acts upon a needle, and which may be measured by various processes, does not depend simply upon the intensity of terrestrial magnetism, but also on the magnetic state of the needle itself. It follows from this, that the determination of this directive force upon a same needle in different points of the globe, would not enable us to know the relative intensities of terrestrial magnetism in these different places, except so long as the magnetic state of this needle shall have remained invariable during the whole course of these observations, which is very rare, or that we are able to know the manner in which it has varied, which is extremely difficult. We understand, therefore, the importance that was attached to our being able to measure, in an absolute manner, the magnetic intensity, independently of the needles, that might be employed for this determination. Poisson had long ago

applied calculation to this question, and resolved the problem by indicating a method to be followed, founded upon the simultaneous employment of two needles; but it is Gauss who, by following an analogous course, was the first to render practical a conception which, before his time, had appeared purely speculative.* We shall return to the application of this method, and in general to the mode that is to be followed to guard against the cause of error that we have been pointing out; but first we must describe the processes themselves, by means of which the directive force of terrestrial magnetism is measured.

Up to the time of the invention of the bifilar magnetometers, by means of which Gauss has been able to determine it with an extreme precision, as we shall see further on, in a function of a foreign resistance, which maintains a magnetised bar out of its position of equilibrium, the only known method consisted in causing a magnetised needle to oscillate. It is to this process we are indebted for almost the entire of the observations made up to this day; it permits of much more portable instruments than magnetometers, and which may be applied, although with less precision, it is true, to the research for absolute intensity.†

The directive force of the globe being exercised in the direction of the inclination needle, it is necessary, in order to find directly the intensity of this force, or rather the relation of the intensities of this force, in two different places, to cause the inclination needle to oscillate around its position of equilibrium. If n and n' are the numbers of oscillations executed in the same time by the needle, by designating the corresponding intensities by G and G', we have, —

$$\frac{G}{G'} = \frac{n^2}{n'^2}.$$

This method has been followed by several observers, and in particular by M. de Humboldt; but it is exact, only so

* *Vide* the final note A. for the development of this method.
† *Vide* the final note A.

long as the weight of the needle is entirely suppressed; besides, the friction, that is considerable in this mode of suspension, and perhaps, also, the magnetism of rotation (induced currents), contribute to stop the needle.

It is therefore preferable, as has generally been practised, to cause the declination needle to oscillate: the horizontal component of directive force is thus determined; and if g and g' now represent the horizontal components in two places where the inclinations I and I′ have at the same time been observed, the total directive forces G and G′ will have as relations,

$$\frac{G}{G'} = \frac{g}{g'} \cdot \frac{\cos. I'}{\cos. I}.$$

M. Gambay's intensity compass (*fig.* 356.) presents a round

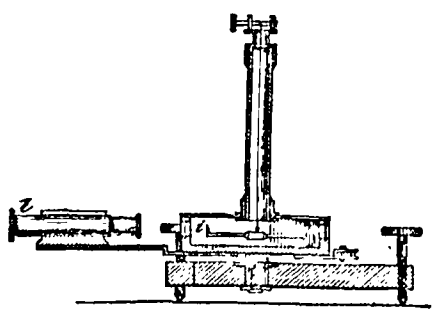


Fig. 356.

wooden case, which is pierced with two openings diametrically opposed. The microscope serves for counting the oscillations of the needle when they become very small. A graduated arc, which is traversed by the extremity of the needle, measures the amplitudes and the manner in which they decrease. The thread, to which the needle is suspended, must be a very fine filament of the cocoon, so as to oppose by its torsion only a very feeble resistance to the movements of the magnet. All the apparatus that have been used in observations of intensity present the greatest analogy to this, and are always composed essentially of a declination needle, the oscillations of which may be counted.

Let us now, in a few words, notice the manner of proceeding in these observations. We make sure that the needle is horizontal; and we move it from its position of equilibrium as nearly as possible in a horizontal plane to an angle of about 20°, for if the primitive deviation were less, we should not be able to count a sufficient number of oscillations, which would prejudice the accuracy of the result. But, on the other hand, the formula of the pendulum, which is employed for finding the intensity of the directive force that acts upon the needle, is rigorous only for oscillations that are infinitely small; so that it is necessary to correct the result, that is to say, the duration observed for a certain number of oscillations, by means of a formula, in which are included the amplitude of the oscillations and the manner in which this amplitude has diminished; we must also take account of the torsion of the thread to which the needle is suspended; and we arrive at this by substituting for the magnetised needle a copper needle, of the same form and weight, the oscillations of which are observed; we thus obtain the corrected duration of the oscillation. It is evident that for these observations, as for all those in which time is one of the data of the question, we must be able to estimate it with great accuracy. There is one more very important element to determine, which is the temperature of the needle during the experiment; we know, in fact, that the magnetism of a magnet diminishes in proportion as the temperature rises; we must, therefore, take account of this cause of alteration in the duration of the oscillations, and be able to reduce to a same temperature all the observations intended to be compared together; for this purpose, each needle that is employed must be submitted to a certain number of experiments; it is made to oscillate while maintaining it successively at different temperatures; and if we are careful always to choose the same hour of the day, we may assume that the terrestrial magnetic force is the same for all the experiments, and that the differences in the duration of the oscillations are simply due to differences of temperature: we thus determine the constants of a formula of correction; this is what M. Kupffer

did with much care. Finally, we have already said that it is essential that the magnetised needle should retain its force without any alteration during a series of comparable experiments, or, at least, that at the commencement and the end, experiments should be made in a same place, in order that we may verify the alterations that have supervened; and, if they were not too abundant, to correct the results by means of interpolation.

When the object is to make observations in a same place, there is a great advantage in employing a new class of magnetic instruments, much superior to the old, both in sensitiveness and in accuracy, and which have been devised by Gauss; these apparatus have been for a long time employed in the magnetic observatory of Göttingen, where they were first established; their use was promptly diffused throughout all Germany, and thence successively into all observatories; it is only by means of these instruments, which enable us to give astronomical accuracy to magnetic observations, that we have been enabled to acquire truly important notions on the variations of the elements of terrestrial magnetism. Their sensibility is due both to the character of the magnets that are employed, as well as to the mode of suspension; their accuracy is due to the particular apparatus by means of which they are observed.

The first of these apparatus is the *unifilar*, or *declination magnetometer*, of which the following is the description. In a room conveniently arranged, and for the construction

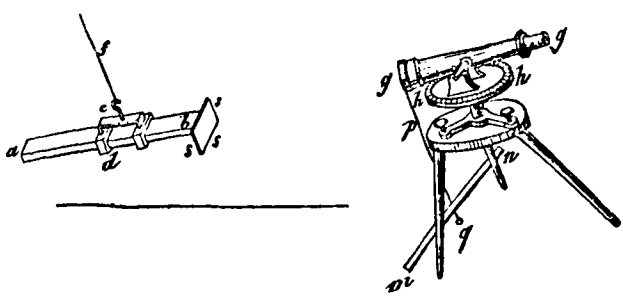


Fig. 357.

of which all employment of iron must have been avoided, is traced (*fig.* 357.) a line, following the direction of the

magnetic meridian; in two points of this line are placed, on the one hand the magnetised bar $q\ b$, suspended at the extremity of a thread $c\ f$, which is rolled round a small pulley fixed to the ceiling; and on the other hand, at a distance of about five yards, a theodolite, $p\ n$, with its telescope, $g\ g$, the optical axis of which is in the magnetic meridian. The magnetised bar, about 23·6 inches in length, carries at the end which faces the theodolite a plane vertical mirror $s\ s$, perpendicular to its magnetic axis; finally, below the theodolite is arranged horizontally a divided scale $m\ n$, facing the mirror, and the zero of which is on the vertical $p\ q$, passing through the object-glass of the telescope; it is the division of this rule whose image is seen in the mirror of the bar; if its magnetic axis is parallel to the line that has been traced, the mirror is normal to it, consequently parallel with the divided scale, and it is the image of zero, which coincides with the point of crossing of the wires of the telescope; but, when the bar is deflected, it is the image of another point of the scale that is found in the optical axis, and it is easy to deduce, from the length comprised between the zero, and the division, that is seen at the same time as from the distance of the scale from the mirror, the angle through which the bar has been turned. We must remark that this mode of observation presents the advantage that, among all the movements of which the bar, and consequently also the mirror, are necessarily susceptible, the angular movement, in a horizontal plane, is the only one that influences the reading of the scale. Without wishing to enter into all the details which the complete description of this apparatus would involve, we may add a few words upon the principal parts of which it is composed, and of which the *figures* 358. and 359. give the vertical and the horizontal projection. The thread is formed of filaments of cocoon in sufficient number to be able to support with the bar a weight of 2¼ lbs., which is added in researches of the moment of inertia. The thread is not fixed directly in the stirrup that supports the bar, but to a horizontal circle called the torsion circle, and upon which the stirrup rests in such a manner that, on

turning this circle, the thread may be brought to be without torsion, still leaving to the bar the direction that is desired.

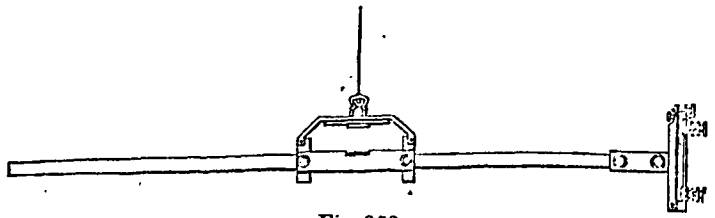


Fig. 358.

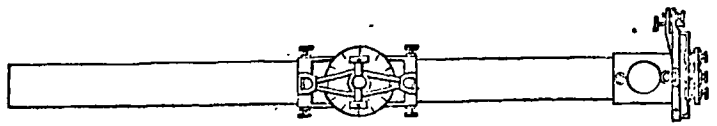


Fig. 359.

All the apparatus is enclosed in a cylindrical box, the lid of which allows the suspension thread to pass, and which presents a lateral opening facing the mirror.

From the great sensibility of the magnetometer, it follows that the bar is always in motion; that consequently it is necessary to substitute for immediate observations, indirect observations, that do not require a complete rest, and to deduce, from the oscillations of the magnet, the position that it would occupy if, at this instant, it were in equilibrio. The most simple process would be, to take the bisection of the angle of the two successive and extreme positions of the bar; but it is far from being exact as soon as the oscillation possesses a certain amplitude; for, in this case, the amplitude diminishes during the continuance itself of the oscillation; and the direction of equilibrium is less near to the former extreme position, than to the latter; if the latter is taken for a point of departure for the second oscillation, the direction of equilibrium, determined in the same manner as the first, would deviate by the same angle from the real direction, but in a contrary sense; it is therefore necessary to take the mean of the two successive means. We may say, finally, that in order to observe the variations of declina-

tion, we merely require a telescope that can be moved on a vertical plane, and be directed at pleasure upon the mirror, and upon a marked point, arranged at a suitable distance in the vertical plane, passing through the line originally traced, so that the observer may be assured that his instrument has not been deranged. In order to measure absolute declinations, a theodolite is employed, by means of which we can look at an object, whose azimuth, in respect to the meridian of the place, has been determined beforehand.

The second of the apparatus, devised by Gauss, is the *bifilar magnetometer*. It was natural to suppose that the intensity of the magnetic force, as well as its direction, was subject to continual variations; but the observations of intensity, of which we have spoken, could only serve to determine its mean value, during the time that the experiment lasted; and it is impossible to contract this time too much, without running the risk of committing a sensible error in the duration of the oscillation; it was therefore indispensable, in order to study the variations of the magnetic intensity, to have recourse to a new method; this is what Gauss did, in inventing the bifilar magnetometer. When a body, suspended by two threads, is submitted to the action of gravity alone, it places itself in equilibrio in a position, determined by the particular conditions which satisfy the points of attachment of the threads, and the centre of gravity of the body itself. If it is deranged from its position of equilibrium, it tends to return to it by virtue of gravity, which is here transformed into a directive force. Suppose now that this body is a magnetised needle, it will assume a position of equilibrium intermediate between that, which would depend only on the mode of suspension, and the direction of the magnetic meridian; and, in this position, we shall know that the magnetic momentum is precisely equal, and contrary to that of gravity, so that we can calculate it*; and whence, consequently, we deduce the directive force, that is acting upon the needle. If its

* *Vide* final Note B.

intensity suffers a change, the position of equilibrium will suffer a change also, and its variations will be thus translated into angular variations. The instrument is so arranged, that, for a mean value of intensity, the bar in its position of equilibrium shall be perpendicular to the magnetic meridian: it follows from this, that the small changes of declination have no influence over this position, whilst the least variations in intensity immediately affect it. The mode of observation is the same as for the magnetometer of declination; namely, we view in a mirror, fixed to the bar, the image of a divided scale; the wires are of steel, and are attached to two points of the diameter of a divided circle, upon which (*fig.* 360.) two transoms, furnished with verniers, are able to turn, one of which carries a vertical mirror, movable around a vertical axis, the other the stirrup, into which the bar is placed *; the various parts of the instrument must be considered as connected invariably with each other, when the variations of intensity are observed; and it is only for the determination of the intensity itself, that we employ the movements of rotation, of which they are susceptible. We shall see, when we are engaged upon this photographic process for the registration of observations, how we may obtain protection from the influence of temperature, which would risk altering the results.

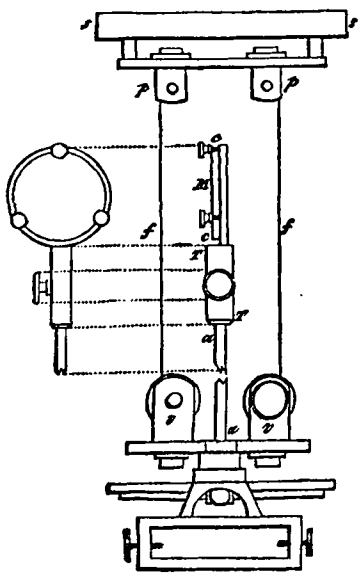


Fig. 360.

When once the declination and the horizontal intensity are determined, by means of the two magnetometers, it would be necessary, in order to render the observation

* *Vide* Vol. I. p. 539.

complete, to know the inclination; for this purpose it is sufficient to determine the vertical component of the magnetic force; since the ratio of the vertical force to the horizontal force of terrestrial magnetism is nothing else than the tangent of the inclination.* With this view has been constructed the instrument known under the name of balance magnetometer. It is composed of a magnetised needle, resting upon agate planes, by means of knife edges, and brought back by a counterpoise to be horizontal; a mirror is fixed to it, and the mode of observation is the same as in the other two magnetometers, except that the deviation observed takes place in a vertical plane. This apparatus is very inferior, in respect to accuracy, to the other two previously described; and it has been abandoned at the Observatory of Brussels; but continues to be observed in those of Greenwich and of Paris.

When there had been established, in a great number of magnetic observatories, instruments sufficiently sensible to detect the least variations of the elements of terrestrial magnetism, the necessity was very quickly understood of observing the phenomena at intervals much closer together than had been done hitherto, and it thus led to apparatus being invented, in which the observations might register themselves. There now exist two principal systems of registering instruments, those in which the indications are obtained by mechanical apparatus, and those in which the inscription is made by means of photography. The former sytem has been for a long time employed in several observatories, and especially in that of Brussels, in which it has given excellent results; it varies much in its details; but whatever perfection may be introduced into the construction of the apparatus, it is impossible to avoid the sensitiveness of the instruments being more or less altered by the intervention and the inertia of the indicating pieces.

The photographic system does not present this inconvenience. Thus, after having been installed at Greenwich

* In *fig.* 360. the mirror is represented in two different planes, perpendicular to each other, and both vertical.

by its inventor, Mr. Brooke, and erected at Toronto, it has just been adopted by M. Leverrier at the Observatory of Paris, where it has been established by M. Liais, under the personal superintendence of Mr. Brooke, but with some happy modifications for permitting direct observations and absolute determinations. By means of an excellent theodolite, well constructed, the absolute declination may always, when desired, be easily obtained; the precautions of stability, taken with this view, are all those of an astronomical observatory. In an isolated pavilion, situated at the south-east angle of the observatory, has been placed a declination magnetometer, a bifilar magnetometer, and balance magnetometer. The magnetised bar of the declination magnetometer is a hollow cylinder of 7·87 in. in length, an arrangement which presents the advantage of furnishing powerful magnets of a feeble weight; for we know that, setting out from a certain limit of thickness, a hollow cylinder is magnetised almost to the same degree as a solid cylinder. The bar being hollow, a collimator telescope is made of it; it carries a lens at one of its extremities, the south; at the other, the north, a horizontal divided scale, which is in the principal focus of the lens; the rays, that come out from it, come out parallel, so that the scale is visible with the theodolite.

Let us now see how the photographic tracing is produced. The bar supports a concave mirror of metal, which moves with it. At 25·59 in. from this mirror is situated a jet of gas, the chimney of which presents a horizontal slit on the side of the mirror. The rays emanating from this slit, and reflected by the mirror, form, at 9·84 feet from the mirror, at the conjugate focus, an image of the vertical slit. The slit is not on the very axis of the mirror, in order to avoid the reflected rays being intercepted by the chimney; but it is slightly deviated. By this arrangement it is seen that the image of the slit moves horizontally, in respect to the centre of the compass, through an angle double that of the bar. A system of two cylindrical lenses of 11·8 in. in length, and with a short focus, is arranged horizontally, so as to concentrate in a luminous point the image of the slit,

without however reacting on the direction of that point. These lenses would have been useless had the source of light been a point instead of a slit; but then there would not have been enough light to obtain a photographic tracing.

Behind the cylindrical lenses is situated a cylinder of 7·87 in. in diameter, covered with photographic paper, and to which a chronometer imparts a rotation of one turn in twenty-four hours. This cylinder receives the luminous point, the displacements of which take place parallel to its axis. The cylinder being animated by a movement of rotation, the luminous point describes at its surface a curve, that is impressed upon the sensitive paper.

On the centre of the inner cover of the cylinder is situated a lens, furnished with a prism, by means of which a second jet of gas, fixed on the same pillar as this cylinder, traces photographically a base line. It is the variation of distance between this base line and the curve—a distance independent of the position given to the papers on the cylinder—which enables us to know the changes of declination. A screen enables us to make small interruptions in the curve, which serve to furnish bases for ruling the scale of hours.

On the same registering cylinder, on the opposite side to the luminous point furnished by the declination compass, is situated a third luminous point, which traces the curve of the variations of horizontal force. This third point is furnished by the bifilar magnetometer, placed on a pillar at the south-west angle of the pavilion.

A similar bar to that of the declination compass is maintained by a suspension by two threads, in a plane perpendicular to the magnetic meridian. Its north pole, that which carries the divided scale, is to the west. This bar is observable with the same theodolite as the declination compass. This arrangement enables us to determine rapidly, in any instant, the exact situation of the magnetic axis of this bar, in respect to the astronomical meridian. In making this determination, for various readings of the torsion circle, we are able to deduce from it the angle of torsion necessary for bringing back the magnetic axis into the plane, perpendicular to the

magnetic meridian. Knowing, then, the weight of the apparatus, the distance apart of the suspension hooks, and the length of the threads, we have, in the function of weight, the value of the torsion pair, that makes equilibrium with the magnetic pair; this latter pair has for its measure the product of the magnetic moment of the bar by the horizontal force of the globe. If, then, according to Gauss's method, we deviate the declination compass with the bifilar bar, in order to deduce from it the relation of the magnetic moment of this bar to the force of the globe, we have the necessary elements for obtaining the measure of the horizontal force of the globe.

The threads of suspension of the bifilar magnetometer are enclosed in a glass tube; they are 3·2 ft. in length. The bar is enclosed in an octagonal glazed box, similar to that of the declination compass. The bar is likewise placed between two plates of copper, and carries, for photographic registering, a concave mirror, in all respects similar to that of the declination compass.

The magnetic moment of a magnetised bar, changing with the temperature and the situation of the bar, depending upon the product of this magnetic moment by the force of the globe, the necessity would follow from this of correcting the curves from the influences of temperature, point by point, if the instrument had not been compensated against the effects of heat. Mr. Brooke has obtained this compensation by causing the torsion pair to vary under the influence of temperature, in the same relation as the magnetism of the bar, whose variations have been previously determined by experiment. For this purpose, it is sufficient to arrange so that the two suspension hooks approach when the temperature rises, an effect that is obtained by the inequality of the dilatation of glass and zinc. The instrument may at pleasure act with or without compensation.

The vertical-force magnetometer is placed at the east of the pavilion. It consists of a collimator bar, similar to those of the other two instruments, and supported on an agate plane by a balance suspension on steel knife edges. These

knife edges are in the magnetic meridian, so that the bar moves in a plane perpendicular to the magnetic meridian. Its magnetism would then tend to render it vertical, but a counterpoise retains it horizontal. The variations of the vertical force of magnetism cause this instrument to incline like a balance; its sensibility depends upon the centre of gravity being near to the centre of suspension, and is regulated at pleasure. As for the bifilar magnetometer, a compensation is required against the effects of temperature; this compensation is obtained by a thermometer carried by the bar, and the dimensions of which have been determined by Mr. Brooke, from the study of the variations of the magnetism of the bar. When the temperature rises, the elevation of the thermometer increases the weight of the side of the north pole of the bar. This thermometer may be removed at pleasure. The situation of the magnetic axis, in respect to the horizon and to the magnetic meridian, may be determined at any time by the theodolite.

The photographic registration is made as for the other instruments, except that the movement of the luminous point, instead of taking place in a horizontal plane, takes place in a vertical plane. This condition has compelled the employment of a vertical cylinder different from that which is used for the other two instruments.

The preparation of the photographic papers is no obstacle to the employment of instruments for continuous indications. At the Observatory of Paris, the moist processes have been abandoned, which compel the preparation of the paper each day, and the causing the impression to appear immediately; waxed papers have likewise been abandoned, which are expensive and long in preparation, on account of the prolonged immersion they must undergo in a bath. It has been determined to obtain proofs on ordinary paper and dry. In a few hours, paper may be prepared for a fortnight; and we may be content to make the impressions appear by gallic acid at the end of each week.

The paper is made sensitive with the iodide and bromide of ammonium, nitrate of silver, and acetic acid. After

having been dried, it is preserved sheltered from light, and is in a condition to be employed. The sheets that are withdrawn from the cylinder are preserved. The images are made to appear with gallic acid diluted, and they are fixed with hyposulphite of soda.

Results of Observations relative to the Determination of the Elements of Terrestrial Magnetism and of their Variations.

After having described the principal instruments intended for the observations of terrestrial magnetism, we are about to pass on to the exposition of the very numerous results that have been furnished by these observations.

Halley is the first philosopher who appears to have formed a just idea of what terrestrial magnetism is; he published a chart of the lines of declination of the magnetised needle in 1701, on his return from a sea voyage, undertaken with the special object of making magnetic observations, in which he visited the *east* and *west* shores of the Atlantic Ocean and several isles of both hemispheres, as far as the ice permitted him to advance. Independently of his own observations, Halley collected with care all the observations worthy of confidence made by others. Setting out from Halley, philosophers continued to occupy themselves with questions relative to terrestrial magnetism; but it is chiefly within about forty years that this study has assumed a very special development. Already the important works of M. de Humboldt had, as we shall see, furnished valuable data upon this subject, when M. Hansteen published at Christiania, in 1819, his great work, *Magnetism of the Earth*, in which, collecting under a single view all anterior observations, he traced charts of declination for the years 1600, 1700, 1710, 1720, 1730, 1744, 1756, 1787, and 1800; and those of inclination for the years 1600, 1700, and 1780. M. Hansteen has continued from that time, and still continues, to contribute without interruption an important contingent of works to this very interesting part of terrestrial

physics. The researches relative to intensity commenced only at the end of the last century, by the observations of M. de Rossel, in the voyage of Encastreaux; then, more recently, by the more numerous and more precise labours of M. de Humboldt: a great number of philosophers have since then been occupied in determining the value, in divers places, of this element of terrestrial magnetism; but the first general chart of the lines of equal magnetic force upon the globe was published in 1837, by Colonel Sabine, who has devoted himself with an uninterrupted ardour and activity for nearly forty years to the study of terrestrial magnetism,—a study into which he entered by four successive scientific expeditions, from 1818 to 1822. Among the other voyages, fruitful for the advancement of this part of science, let us note also, in the first rank, that of Captain Duperrey in the *Coquille*, from 1822 to 1825, undertaken with the view of tracing, all around the oceanic portion of the globe, the lines of no declination; the expedition made by MM. Hansteen, Ermann, and Due, from 1827 to 1829, in Eastern Siberia, in order to determine at this epoch the position of the most feeble magnetic pole in the northern hemisphere; the expedition, from 1840 to 1845, of Captain J. Ross; and, subsequently, those of Captains Moore and Clark, with the view of learning the positions of the south pole of magnetic force: and, more generally, in collecting the materials necessary for tracing magnetic charts of the southern hemisphere, the voyage and the sojourn of MM. Bravais and Lottin in the polar regions, and, in particular, their magnetic observations at Bosseкop (Finmark); the magnetic triangulation of the Britannic possessions in the north of America, made by Lieutenant-Colonel Lefroy, from 1843 to 1844; and, finally, that of the Indian Archipelago, undertaken by Captain Elliot, from 1846 to 1850, at the expense of the East India Company, and the object of which was to obtain an exact magnetic chart of the three elements, in this region of the globe, in which they had never been studied. To these various expeditions, it would be necessary, in order to be complete, to add also the magnetic observations made for

several years by numerous travellers and navigators, and of which several will equally serve our purpose.

Beside the voyages and expeditions, we must not forget, as having rendered a great service to the science, the establishment of numerous magnetic observatories on different points of the globe, and the multiplication of which was essentially called forth by M. de Humboldt's letter of April, 1836, to the Duke of Sussex, then President of the Royal Society of London. M. de Humboldt insisted in his letter on the utility of increasing the number of permanent stations, in order to obtain the greatest number of corresponding observations — a very great advantage, especially in so far as concerns the variations, whose simultaneity may thus be studied. Many magnetic observatories were then instituted in addition to those which already existed, and of which the most remarkable was the Observatory of Göttingen, directed by Gauss and Weber. Among those recently instituted, we will cite, principally, four, which have been selected so as to be situated under very different circumstances of magnetic intensity, and in an opposite position, in respect to the poles and to the magnetic and geographical equators. The first of these observatories was constructed at Toronto (Canada), and the second at Hobart Town (Van Diemen's Land). These two stations were chosen because they are situated almost at the antipodes of each other, and because they are sufficiently near to the points in which the magnetic force possesses its maximum of intensity. The third observatory was established at the Cape of Good Hope, an important point, on account of its situation at the southern extremity of Africa, and because the magnetic elements there undergo great variations. Finally, the fourth observatory was placed at St. Helena, between the two tropics, at a small distance from the equator, and at a place in which the magnetic intensity is feeble. It is under the direction of Colonel Sabine that numerous observations are pursued in these observatories. By means of all these resources, added to the perfection of the instruments employed, and which we have described in our First Paragraph, we have succeeded in

determining the magnetic declination, inclination, and intensity of a very great number of points of the surface of the earth, and in tracing on the terrestrial sphere *isogonic* lines, or lines of equal declination; *isoclinic*, or lines of equal inclination; *isodynamic*, or of equal intensity. It is not only declination, inclination, and intensity that have been successfully observed, but also the continual variations which these elements suffer in a same place, either from one year to the other, or in the divers months of a same year, or in the different hours of a same day.

It is indeed of importance, when we compare observations made in one place with those made in another, for the determination of the absolute elements, to know at what epochs they have been made, since in a same place the three magnetic elements do not remain constant. Thus the declination, which is the element most anciently observed, was, at Paris, in 1580, the most remote period at which it has been determined, 11° 30′ to the east; in 1653, the needle was found to be in the terrestrial meridian, the declination then became western, and it attained its maximum (20° 34′) in 1814, an epoch, setting out from which, it diminishes each year. It appears from ancient observations that, in Belgium, the magnetised needle deviated to the east of the meridian, about 15° in 1568, and that towards 1600 it still deviated 9°. At London, and, which is very curious, at the Cape of Good Hope, consequently, in the other hemisphere, the declination has followed a similar march, that is to say, that at first to the east, it is then led to the west; only, at the Cape, it would have passed sooner to the west, and would likewise sooner attain its maximum to the west; whilst, at London and at Paris, the two maxima to the west took place sensibly at the same epoch. In London, the declination which, in 1576, was 11° 15′ to the east, was, in 1652—1667, 0°; and 24° 20′ in 1813 and 1814 (maximum). At the Cape it was 0° 30′ to the east in 1605; 25° 40′ to the west in 1791 (maximum); 25° 4′ to the west in 1804. We shall see, further on, the law which the present diminution of the

declination seems to follow, and which is about 6′ per annum.

Nor is the inclination of the magnetised needle any more constant in the same place; but it has undergone, for more than two centuries that it has been observed, a regular diminution; thus, after having been at Paris, 75° in 1671, it was no more than 70° 52′ in 1791, and 66° 25′ in 1851. The inclination has in like manner diminished in Brussels regularly since 1827, in which it was 68° 56′ 5″, to 1854, an epoch at which it was no more than 67° 45′. M. Hansteen believes that the inclination will attain a minimum, setting out from which it will cease to diminish, in order to recommence increasing. This minimum state is already found to be attained in Russia; it should present itself next at Stockholm and at Christiania, then later at Copenhagen, and in the more southern cities. M. Kupffer has found a confirmation of the ideas of M. Hansteen in observations made recently in Siberia and at Kasan, and especially at Pekin, where the inclination has been increasing for a long time. According to M. Quetelet's calculations, made upon numerous observations, the annual diminution of inclination is 3′.87 at Milan, 3′.8 at St. Petersburg, 3′.7 at Paris and Berlin, 3′.56 at Christiania, 3′.5 at Turin, and 3′.4 at Brussels, &c.

With regard to intensity, it also plainly appears to suffer variations; thus M. Arago has found that it went on increasing from one year to another: but this augmentation, if it exists, is very feeble; for M. Quetelet has not perceived that this element has suffered any very sensible alteration for a quarter of a century that he has been observing it.

The *secular* variations, of which we have just been speaking, are altogether different from the *annual* and the *diurnal* variations; to which we shall return when, in taking account of the secular variations, we shall have cast a glance upon the present magnetic state of the different points of our globe under absolute relations.

Every place of the earth is therefore characterised, in the magnetic point of view, by three elements,— declination, in-

clination, and intensity. We might content ourselves with giving a Table that should contain the value of these three elements, for all the points of the globe, where they have been determined by selecting determinations made, as much as possible, at the same epoch. But this proceeding would not give us a general idea of the distribution of the magnetic forces upon the surface of the earth; thus we prefer essentially, with M. Hansteen and with M. Duperrey, who have employed slightly different methods, to follow successively the march of magnetism from one point to another.

Admitting that, if the magnetised needle assumed, in all points of the earth, the north-south direction, we should not hesitate to say that the earth possesses magnetic poles, which coincide with the geographical poles, M. Hansteen is led to inquire, what ought to be the position of these magnetic poles, in order to explain the fact, proved by accurate observations, that the needle deviates from the meridian; that this deviation is not the same everywhere; that it is more eastern in some places, more western in others; finally, that it varies with time in a same place. The declination is now western throughout all Europe; if, then, setting out from St. Petersburg, in which it is 8° to the west, we advance from the east to the west toward Greenland, we see it increase, being 15½° at Stockholm, 20° at Christiania, 24° at London, about 40° on the north coast of Iceland, and about 51° in the colony of Godthaab in Greenland. From the west coast of Greenland to Hudson's Bay it decreases gradually; then, if we advance on the Continent, it disappears entirely; becomes eastern, and increases rapidly toward the west coast of America. In prolonging the lines that indicate the direction of the magnetised needle, we see that they meet in a same point, about 20° distant from the pole of the earth, and about 259° east of Greenwich, which gives for this point a north latitude of 70°, and a west longitude of 101°. But, on the other hand, if we follow, in the north, the coast of Norway, we see the declination decrease, and finally disappear entirely in the White Sea; and, if we trace prolongations of the directions of the needle in these divers

points, the lines no longer go and pass through the point determined above; it is the same with the prolongations of the directions of the needle in the northern parts of Behring's Straits, and in the north-east part of Siberia. We are thus led to suppose, somewhere in the sea of Siberia, a second magnetic pole, which attracts the north pole of the needle toward the east between Spitzbergen and Norway, toward the west in Eastern Siberia and in Behring's Straits.

It follows, from the various observations collected by M. Hansteen, that the western declination disappeared entirely in 1805, before arriving at Kasan; from Kasan to Tobolsk, the eastern declination increased; and it decreased anew toward Irkutsk, where it was not more than half a degree; more to the east, it should entirely disappear, for at Jakutskoi, Billings* found, in 1788, a western declination of 2°; finally, at the east of Jakutskoi, this western declination disappears again, and again becomes eastern in Kamtschatka and in all the north-west part of America. There are, then, four points around the northern pole in which the declination is null: the first, upon the western coast of Hudson's Bay; the second, upon the line that joins Kasan to the White Sea; the third, a little to the east of Irkutsk; and the fourth, a little to the east of Jakutskoi. Between the first and the second, namely, in the north-east part of America, upon the Atlantic Ocean, and in all Europe, the declination is west; between the second and the third, namely, in the greater part of Siberia, it is east; between the third and the fourth, namely, in Eastern Siberia, it is west; between the fourth and the first, namely, in Kamtschatka, in the north part of the Pacific Ocean, and in the north-west region of America, it again becomes east.

The position attributed by M. Hansteen to that magnetic pole, which he assumes to exist in North America, agrees with the observations made by Captains Ross and Parry; for, on August 22. 1819, Captain Parry found the declination of 129° west, under a latitude of 70° 40′ north, and a

* There is some doubt on the accuracy of this observation, from which M. Hansteen has drawn some important conclusions.

longitude from Greenwich of 91° 47′ west; and, on August 28., he found it 166° east, under a latitude of 75° 9′ north, and a longitude of 103° 45′ west; whence it follows that, between the 22nd and the 28th of August, the declination must have risen somewhere to 180° before becoming east, from having been west; and that the observers must have passed at some degrees north of the principal magnetic pole, which assigns to this pole a position entirely similar to that attributed to it by M. Hansteen.

The observations of the inclination of the needle confirm this result; for it is evident that the inclination needle must assume a vertical position when over the pole, if the pole is the point of convergence of the forces by which the needle is directed. Now, Captain Ross found, in the scientific voyage which he accomplished from 1829 to 1833, that the inclination was 90°, at a point whose distance from the pole was 19° 55′, and whose longitude was 96° 45′ 18″ west of Greenwich; only it would result, from the difference of longitude, that this magnetic pole would have a movement from west to east, which, moreover, M. Hansteen had already concluded, from preceding observations, both for this pole as well as for the second pole situated in Siberia.

M. Hansteen, by means of magnetic observations made in the southern hemisphere, has succeeded in recognising there also the existence of two magnetic poles, having a movement toward the west instead of having it toward the east: one of these poles is situated toward the south of New Holland, and the other to the south of Terra del Fuego. In designating the magnetic pole of the southern hemisphere, situated to the south of New Holland, by A, and that of the same hemisphere, situated to the south of Terra del Fuego, by *a*; the magnetic pole of the northern hemisphere, situated in the north-west part of North America, by B, and that which is in the north-east part of Siberia by *b*, we find a very curious approximation, namely, that A and B are very nearly diametrically opposed to each other; for each of them is about 20° distant from the pole, and A is in the meridian of 136° east, B in that of 260° east of Greenwich, which

establishes between them a difference of 124° in longitude. The points *a* and *b* have also a situation relatively similar, although, however, presenting not so great an analogy: the distance from the former to the south pole is 13°, that from the latter to the north pole, a little more than 40°; the longitude of the former is 237° east, and that of the latter, 116°, which establishes a difference of longitude between them of 121°.

According to M. Hansteen, the earth should have two magnetic axes, the extremities of which would form the four poles that we have just been recognising—two situated in the northern hemisphere, moving from west to east, and two situated in the southern region, moving from east to west; but there would exist a great difference in the promptitude of their displacement.* By means of these movements of the magnetic poles, the variations would be explained of declination and inclination which would arise from the approximation or the recession of the poles in each hemisphere, and consequently from the change, for a same place, in the predominance of one over the other. Thus, for example, the declination would become west in our hemisphere, when the magnetic pole, B, of America approaches Europe at the same time that the pole, *b*, of Siberia recedes from it; formerly it was east, the latter pole being nearer to Europe. Thus, the inclination diminishes in Europe by the effect of the displacement to the east of the pole of Siberia, whilst it increases in Eastern Siberia and in Kamtschatka.

The variations of declination and inclination in the southern hemisphere are likewise justified by the movements attributed to the magnetic poles. Thus, at the Cape of Good Hope and in the bays that are in its neighbourhood, the declination was east in the days of Vasco de Gama†; then it became west, and rose to more than 25°, which is due to

* M. Hansteen assigns to these revolutions of the poles the following durations: to the pole A, 4609 years; to the pole *a*, 1304; to the pole B, 1740; to the pole *b*, 860.

† In the southern, as in the northern hemisphere, we call that eastern declination, in virtue of which the north pole of the needle is deviated to the east, and the south pole consequently to the west; in a word, it is the north or *marked* pole, as the English call it, which is the one whose movements we regard always and in all cases.

the fact that the American pole, *a*, receded, whilst that of New Holland, A, approached. It is also to the movement toward the west of the pole *a*, that is due the augmentation of southern inclination in all South America.

After having established, by the phenomena of declination and inclination, the existence of four magnetic poles, or rather, of four centres of convergence of the magnetic forces of the globe, M. Hansteen endeavoured to show that the phenomena of intensity lead to the same conclusion. Already had Humboldt, in 1799, found that the magnetic intensity was at its minimum at a point situated about 7° south of the equator in Peru, and he took for a unit this minimum intensity. In 1805, Humboldt, by fresh observations made in Europe conjointly with Gay-Lussac, established the law, that the magnetic intensity went on increasing from the equator to the poles. To these documents, and to others besides, we must especially add the observations of Major-Gen. Sabine upon the Atlantic, setting out from 12° south latitude to the most northern coast of Spitzbergen. By means of all these observations and his own, which he made in a voyage in Siberia, M. Hansteen succeeded in tracing *isodynamic* lines, the inspection of which shows that, upon a same parallel, the intensity is much greater in America than in Europe; that, in America, the isodynamic lines are almost parallel to the equator, whilst in the Atlantic they mount up toward the north, then in Europe approaching to parallelism with the equator. The study of these lines confirms the existence of two magnetic centres or poles; with this difference only, that the magnetic centre of the region west of North America possesses an intensity remarkably more considerable than that of the region east of Siberia. The small number of observations of intensity in the southern hemisphere, which M. Hansteen had at his disposal, was nevertheless sufficient to enable him to recognise also two maxima of intensity at the same places, where the declination and inclination had caused the presumption of the existence of two magnetic poles.

It is evident that on each meridian there must be a point at which the intensity is at its minimum,—a point which, in

general, should not be far from the equator, since the intensity likewise increases in proportion as we approach the north, and in proportion as we approach the south; but the place of the minimum is not the same on each meridian; and among the minima there are some smaller, one than the other. Thus, under the 300° meridian, the intensity decreases from 1·8, its value near New York (40° lat. N.), to 1·0, its value at 7° lat. S. in Peru; then, it increases to the south of this point up to 1·6, its value in Terra del Fuego. Under the 40° meridian, the intensity decreases from the value 1·55, on the most northern coast of Spitzbergen, as far as 20° or 30° of south latitude, where it is not more than 0·8, a value which appears to be that of the smallest of the *minima;* whilst the minimum that is found under the 280° meridian, near to the equator, which is a little above 1·0, would be the greatest.*

Thus, in each hemisphere, the intensity has a double *maximum;* the inclination has likewise a double *maximum* and a double *minimum* on each geographical parallel; and these points are found on the same meridians as the analogous points for intensity. Thus, for example, on the 60° parallel of north latitude the inclination is about 82° in Hudson's Bay, and 72° between Stockholm and Abo, 75° on the meridian of Irkutsk, then 70° at Kamtschatka. In like manner, on the 50° parallel of south latitude, the inclination is over 60° on the 280° meridian; it is about 51° on the 340°, and about 75° in New Holland. The direction of the horizontal needle agrees equally, as we have seen, with the inclination, and, consequently, with the intensity, in the designation of the four magnetic poles.

* M. Hansteen had thought, founding his opinion upon the intensity 1·8 observed by Major-Gen. Sabine at New York in 41° lat. N., and upon that 1·6 (not corrected) observed by M. de Rossel at Van Diemen's Land, in 43° lat. S., that the magnetic intensity should be generally more considerable in the northern than in the southern hemisphere. M. Duperrey, as the result of his observations, has made the 1·6 line of intensity, which passed through Van Diemen's Land, mount up nearer to the equator, and has substituted for it the 1·8 line, which no longer permits us to admit the difference of intensity pointed out by M. Hansteen. We shall even see that, if there is a difference, it is in favour of the southern hemisphere.

We conceive that, in the manner in which he presents to us the phenomenon of terrestrial magnetism, M. Hansteen cannot recognise a *magnetic equator* in the line, that passes through all the points, in which the inclination is null; it could possess this quality only so long as there should exist but one magnetic axis; but, as his observations lead him to recognise that the earth has two, these axes have each their equatorial plane, and these two planes cut each other, following a right line, at the extremities of which the inclination needle must be horizontal; in every other point, the line without inclination must be situated between the two equatorial planes, nearer to that which belongs to the more energetic axis. The line without inclination does not therefore belong to a plane, but to a surface of double curvature, the inflexions of which must change, in proportion as the relative situation of these axes is modified.*

Halley had already, before M. Hansteen, shown the impossibility of reconciling the differences of declination observed in the southern hemisphere, with two poles, and the necessity of assuming four in order to give a complete explanation of all the phenomena of declination observed upon all the points of the globe. He had even assigned the position of these poles, which possesses some analogy with that which has been determined by M. Hansteen. Halley designated by *magnetic poles* the points of the surface of the earth considered as a magnet, in which the resultant of the forces of all the parts of the globe attains a maximum.†

* M. Hansteen has traced upon the intensity chart the line upon which the inclination is null, both according to the observations of 1775 to 1780, as well as according to the more recent ones of 1822 to 1830. These two lines do not in any way accord; they cut each other in four points, the position of which indicates a movement of undulation, which is repeated in the other curves of inclination, and which is a necessary consequence of the displacement of the poles. The idea of some philosophers, of a simple movement of translation to the west of an assumed single magnetic equator, can therefore in no way explain the changes in the magnetic state of the globe.

† Gauss, in his theory of terrestrial magnetism, admits only two magnetic poles; but by this word poles he understands two points, in which the magnetic intensity, that is to say, the horizontal component of this intensity, is null, and where, consequently, there is nothing beyond the vertical component. The first is situated in the north of America, at 70° 35′ of north latitude, and 264° 21′ of longitude east from Greenwich; this would be very nearly the pole B of Hansteen: the second, to the south of Van Diemen's Land, is 72° 35′

Major-Gen. Sabine — whose works, as numerous as they are remarkable, upon terrestrial magnetism have acquired for him in this matter unquestioned authority — also assumes the four poles as a consequence of the results of all the magnetic observations made upon the divers points of the surface of the globe; but he does not define them as Halley and M. Hansteen have done; they are to him simply points of greater magnetic intensity for two systems, which are distinguished from each other by the difference in the degree of the secular variation to which the phenomena appear to be subject in each of them.

The method by which M. Hansteen has determined the position of the magnetic poles, is not free from every objection. M. Kupffer justly remarks that, if two magnetic poles are adopted in each hemisphere, the needle will be turned neither toward one of the poles nor toward the others, in the greater part of the points of the globe, but will take a mean direction; it will be very difficult then to choose, among the declinations, those whose points of convergence indicate exactly the position of the magnetic pole. By supposing that it was a single pole, which acts at the same time upon the needle, it would be impossible that the declination, in advancing from the west to the east, should be first west, then null, then east, and this upon points very near to each

of south latitude, and 152° 30′ of west longitude. There are, besides, three points, in which the total magnetic intensity is at its maximum relatively to the neighbouring points, two of which are situated in the northern and one in the southern hemisphere. The first is at 16° to the south of the magnetic pole, at 54° 32′ of north latitude, and 261° 27′ of east longitude. The second is situated at 71° 20′ of north latitude, and 119° 57′ of east longitude in Siberia, in the region in which Hansteen conjectured that there was a second pole. The third is placed at 2° 26′ to the north, and 7° 56′ to the east of the southern magnetic pole. The total intensity in these three points, estimating that of London at 1·372, is respectively 1·7634, 1·6918, and 2·2605; whilst at the two magnetic poles, north and south, it is 1·701 and 2·253. There are two points in the vicinity of the equator in which the magnetic intensity is at its *minimum*. They are situated, one in the Pacific Ocean, in 5° 7′ of north latitude and 178° 28′ of west longitude; the other near to the island of St. Helena, in 18° 9′ of south latitude and 350° 12′ of east longitude; their respective intensities are 0·9296 and 0·8094. The line that joins the points, in which the magnetic inclination is null, cuts the equator nearly diametrically at about 8° and 188°; but the two points where it recedes most from the equator are not placed diametrically, and are situated, the former at about 14° 43′ of north latitude and 52° of longitude; the latter in 15° 4′ of south latitude and 320° of longitude.

other, as is found in Eastern European Russia; or even first east, then null, then west again, as happens near to Irkutsk. Besides, M. Kupffer is little disposed to admit the existence of magnetic poles, properly so called, that is to say of centres of magnetic actions, near to the terrestrial poles; he would rather incline toward Gauss's idea, that all the mass of the earth is magnetic.

Nor does Mr. Barlow—who has collected together the most important observations, relative to declination, made in recent voyages, taking care to throw out the errors arising from local attraction—any more admit four magnetic poles in each hemisphere; besides, he occupied himself particularly in tracing out isogonic lines, that is to say lines of equal declination, and the changes which they undergo on the surface of the globe. He finds in the Indian Ocean a line without declination, which cuts the equator, and the curvature of which is extraordinary; the lines of equal declination, situated to the left of this, have a western declination, those which are to the right an eastern. It has been also noticed that, in this same ocean, for 40 degrees, the line without declination marches almost parallel to the equator, and that, for 40 other degrees, it returns into the meridian; but as, when there is no declination, it is necessary that the pole, that is to say the centre of attraction, should be to the meridian of the place, it follows that this pole must, for 40 degrees, coincide with the terrestrial poles; which is little compatible with the existence of four poles.

It would appear that it was about the year 1660 that the line without declination would have traversed the Atlantic Ocean almost at right angles with the meridian of our countries, as is seen at the present time in the Indian Ocean. Since this time, it has gradually been descending toward the south and toward the west; and, at the present time, it traverses the eastern part of South America; it likewise traverses Australia, where for sixty years it does not appear to have undergone any modification.

To sum up, whatever may be the opinion that is formed upon the existence and the number of the magnetic poles, it

follows, from the researches of M. Hansteen, that there exist two lines without declination *, one situated in the Atlantic Ocean, which commences under the 60° of north latitude, to the west of Hudson's Bay, advances in the direction of south-east, through the lakes of North America, traverses the Antillas, and Cape St. Roch, until it reaches the South Atlantic Ocean, where it cuts the meridian of Greenwich in 65° of south latitude. This line is almost straight as far as the vicinity of the eastern part of South America, where it curves a little above the equator. The second line without declination, which is full of inflexions, commences at the 60° of south latitude, above New Holland, which it traverses, extends into the Indian Archipelago, dividing itself into two branches, which cut the equator three times. It first passes to the north of this latter, to the east of Borneo; it then returns, and passes to the south, between Sumatra and Borneo, and again traversing the equator, below Ceylon, whence it passes to the east, in the middle of the Yellow Sea; it then directs itself along the coast of China, afterwards re-descends anew to the north, making a great semicircular elbow, which terminates in the White Sea. Besides, the determination of the variable positions of the lines without declination has no other use than to indicate, by their change, that of the direction of the magnetic forces upon the whole of the surface of the globe. But, in order that this determination may be very exact, it would be necessary to know which, at the same moment, are all the points, in which the declination needle is exactly directed to the plane of the terrestrial meridian.

The conception of the magnetic poles — convenient, in order to fix the ideas upon the direction of the forces of terrestrial magnetism — possesses, however, the inconvenience of leading one to consider these poles as being veritably centres from which the magnetic forces emanate, which is not the case; on the other hand, it does not possess the advantage, as it

* It has been generally admitted that there existed upon the globe three lines without declination; but it follows, from the labours of M. Hansteen, that two only are well determined, and that the third could comprehend only a very small number of isolated points.

seems, of satisfying all the exigencies of the observations. Thus, M. Duperrey has endeavoured to represent to himself the magnetic state of the different points of the globe in a manner independent of all ideas as to the position and the number of the magnetic poles. Setting out from any point, and always travelling in the direction of the magnetised needle, first toward the north pole, then toward the south pole, and noting all the points through which he has passed, he forms a curve, which connects all these points, and which is to him a magnetic meridian. Then taking another point, near to the former, he traces in the same manner a second magnetic meridian, which necessarily meets the former in two points, situated, one toward the north pole, the other toward the south. In tracing upon the globe a certain number of these meridians, and taking the points of intersection of two neighbouring meridians, we have in each hemisphere a closed curve resulting from the reunion of all these points of intersection; and we may, if we please, assume that the magnetic pole of each hemisphere is situated in the centre of the area enclosed by these curves. M. Duperrey has traced upon the same charts, besides the magnetic meridians, curves normal to the meridians, and which he has called *magnetic parallels*. The one of these perpendicular curves, that passes through the middle of the meridian, would be the magnetic equator; but it differs from the curve, that passes through all the points of no inclination, to which the name of magnetic equator has been generally reserved, and from that which passes through all the points of minimum intensity, which in like manner is not exactly the same as that of no inclination, although the name of magnetic equator has also been given to it.

The lines of equal inclination, or isoclinals, would be the true magnetic parallels, analogous to the terrestrial parallels, if the line of no inclination were considered as the magnetic equator. But they are not regular, and are less parallel with each other, in proportion as they approach nearer to the polar regions.

M. Duperrey considers that the lines of equal inclination

possess, like that of equal declination, the inconvenience of not being the expression of a fact, depending simply upon the action of magnetism; for they express two facts at once, one which depends simply upon the action of magnetism, the other upon the particular direction that each vertical follows. The line without inclination cannot therefore, according to this, be considered as the magnetic equator; however, M. Duperrey, having sought for what would be the figure of the veritable magnetic equator, namely of a curve, which would depend upon no cause foreign to magnetism, and, consequently, whose condition would be to be perpendicular to all the magnetic meridians, and whose mean of north and of south latitude would be zero, which is nearly the mean of the latitudes of the line without inclination, he found that this curve does not greatly differ from the line without inclination. The mean plane of this new curve makes, with the plane of the terrestrial equator, an angle of 10° 54′, and its axis, which seems to express the direction according to which the globe is magnetised, pierces the surface of the earth in two points, situated in the polar regions, one at 79° 6′ north latitude and 71° 31′ west longitude, the other at 79° 6′ south latitude and 108° 28′ east longitude. Now, the mean plane of the veritable line without inclination, such as M. Duperrey has traced it, by means of two hundred and seventy observations which he has collected, makes an angle of 10° 49′ with the terrestrial equator, and pierces the surface of the globe in two points, situated, one at 79° 11′ north latitude and 78° 10′ west longitude, the other at 79° 11′ south latitude and 101° 40′ east longitude; the difference, therefore, is not very great between these two planes.* We must, how-

* It results from the labours of M. Duperrey that the line without inclination (magnetic equator) meets the equinoctial line in two points only, which are almost diametrically opposite, and situated, one in the Atlantic Ocean, the other in the Pacific Ocean, almost in the plane of the meridian of Paris; that, where this equator encounters only a few scattered isles, it is distant but very little from the equinoctial line; that it recedes more when the isles are multiplied, and does not arrive at its maximum of excursion, either to the north or to the south, except in the two great continents, which it traverses; that, finally, there exists between the southern and northern sections of this singular curve a remarkable symmetry, much more perfect than had been at first supposed.

ever, remark that the extremities of the axis of the magnetic equator, such as it results from the line without inclination, as well as from the line perpendicular to the magnetic meridians, do not coincide with the points of the surface of the globe, where the needle assumes the direction of the vertical, and which for this reason are termed magnetic poles. In effect, M. Duperrey, having been able, in his researches on magnetic meridians, to determine exactly the position of these points, has found that one was situated at 70° 10′ north latitude and 100° 40′ west longitude *, and the other at 75° south latitude and 136° east longitude. We remark, with reason, that the non-coincidence of the poles with the extremities of the axis of the magnetic equator is not a reason for dismissing the idea that terrestrial magnetism arises from two centres of action, provided that these centres are near to the centre of the earth; for it is enough for these two centres to be upon a chord near and parallel to the axis of the magnetic equator, in order that the magnetic poles of the surface shall be at the extremities of a second chord nearly parallel, but situated beyond this latter, in relation to the centre of the globe.

We have already seen that one of the circumstances that complicate the study of magnetism upon the terrestrial globe is the want of parallelism between the lines of equal inclination and those of equal intensity †,—a constant want, and which does not arise from accidental irregularities. This point had already resulted from the observations of M. de Humboldt; it follows likewise from M. Hansteen's researches, as we have remarked. M. Duperrey, who has completed the work of M. Hansteen upon isodynamic lines, as far as concerns the southern hemisphere, has obtained, in this respect, some results, the accuracy of which is found to be perfectly confirmed by the quite recent observations of Captain

* This determination is very near to that which was obtained directly by Captain Ross, and which is in 70° 5′ 17″ of north latitude and 96° 45′ 18″ of west longitude.

† There nevertheless exists, as we have established in the first paragraph, an intimate relation between the inclination and the intensity. (See above, p. 217.)

Fitzroy. A very important principle, which M. Duperrey has made evident, is, that these isodynamic lines cut at right angles the directions of the declination needles or magnetic meridians; it is, therefore, these lines which would be the veritable magnetic parallels. The magnetic equator would then, consequently, be the line passing through the points of all the meridians whose intensity is the smallest; which does not mean that this minimum intensity is everywhere the same, for it varies from unity to 0·867; also the isodynamic lines, vicinal to the magnetic equator, come and terminate in it obliquely, without passing beyond. In substance, although the line of the smallest magnetic intensities is not the same as the line without inclination, these two curves are not very far distant from each other, according to M. Duperrey's opinion, as we have seen above, when we showed that there is no great difference between the magnetic equator, such as M. Duperrey defines it, and the magnetic equator determined either by the line without inclination or by the line of minima intensities. We have already remarked that M. Duperrey differs from M. Hansteen, not only in that he does not believe it necessary to admit four magnetic poles, but in that he finds that the mean magnetic intensity of the southern hemisphere is superior to that of the northern, the former being 1·0152, if the latter is represented by unity.

The question of magnetic intensity is in substance that, the study of which may throw the greatest light upon terrestrial magnetism; indeed, of the three species of magnetic lines — lines of equal declination, lines of equal inclination, and lines of equal intensity — the latter are the most important; for they express the equality of the magnetic resultants in all the points of the surface of the globe through which they pass, and independently of every other consideration foreign to magnetism, which does not take place with the other two species of lines. But we must bear in mind that the exact determination of intensities presents great difficulties when the purpose is to compare that of one place with that of another; and there sometimes follows from this, divergences among the observations which compel us to leave certain questions in

suspense. Thus, according to Captain Fitzroy, the magnetic intensity would be a little more feeble at the island of St. Helena than at the island of Ascension, through which passes the line without inclination; whilst the contrary fact actually follows from the observations of M. de Tessan. However, the science possesses a very great number of determinations of intensity worthy of every confidence, and we have already indicated several of them when speaking of M. Hansteen's isodynamic lines; without repeating them, let us confine ourselves to remarking, that the relation which exists between the weakest and the strongest intensity is higher than the relation of 1 to 2; in fact, the intensities observed at New York and at Hobarton, compared with those of St. Helena, are as 1·81 is to 0·84, or as 2·16 is to 1; it is even probable that this relation may rise to that of 2·5 to 1.

It follows, as we have seen, from the numerous researches upon magnetic intensity made by Humboldt, then by Humboldt and Gay-Lussac, and, after them, by MM. Hansteen, Sabine, Ermann, Quetelet, Forbes, and many others, that the intensity goes on increasing in proportion as, receding from the equatorial regions, we approach the polar regions. The following is the actual law of the variations that may be deduced from the Table of Observations, from the magnetic equator to the northern magnetic pole: —

Inclinations.	Intensities.
0°	1·0
24	1·1
45	1·2
64	1·3
73	1·4
$76\frac{2}{3}$	1·5
81	1·6
86	1·7

It would be interesting to know the influence of elevation upon the magnetic inclination and intensity. Unfortunately, the observations fitted for the solution of this question are wanting. It had been fairly concluded, from the observations made by MM. Biot and Gay-Lussac in their aërostatic voyage, that the decrease of magnetic force, at the height to which they

had attained, was not sensible. But attention had not been paid to the fact that, the difference of temperature being 72° between the surface of the ground and the aërial region in which Gay-Lussac caused his needle to oscillate, this needle had acquired a more powerful magnetism, by the effect of the fall of temperature, which would necessarily have caused it to oscillate faster, if terrestrial magnetism had acted upon it with as much intensity as near the ground. This velocity having remained the same, we must conclude from it that the magnetic force of the globe did diminish with the height. This diminution of the magnetic force with height results likewise from the observations made in 1829, at the summit of Mount Elbrouz (in the Caucasus), by M. Kupffer. It is probable, also, that we must attribute to the diminution of intensity the diminution of inclination, that I have had the opportunity of observing at the Hospice of the Great St. Bernard, in 1829, with Professor Gautier, by means of an excellent inclination compass of Gambey's. I had found at Geneva, on July 15th, that the inclination was 65° 42′ 8″; at the Great St. Bernard, from observations made on July 20th and 21st, it was 65 °9′ 8″, which makes a difference of 33′ between Geneva and St. Bernard; allowing for the difference of 22′ of latitude, 16′ 8″, as direct observation indicates it is necessary to do, there remains a difference of 16′·2, due simply to the difference of height. Shuckburgh had already found a difference of 20′ between the inclination at Geneva and the inclination at the summit of the Mole. In these two cases, we cannot attribute the difference to an attraction, exercised by the mass of the mountain, when the observation is made at the base, because the lower station (Geneva) was sufficiently distant from the vicinity of the mountains, that their action upon the magnetised needle might be regarded as insensible. There is no doubt, however, that the different magnetic elements, and, in particular, the intensity, are influenced in many cases by local circumstances; this results, moreover, in an evident manner, from the researches both of Mr. Forbes, as well as of M. Bravais, upon the decrease of horizontal intensity with the height. Mr.

Forbes has deduced, from a long series of observations, which he has made in the Alps and in the Pyrenees, a co-efficient of diminution equal to 0·000034 per hundred English feet; but M. Bravais calculates that this co-efficient is too great for the Alps; from his own observations, the decrease with height, in stations which surround Mont Blanc, would at most be only 0·001 per kilomètre (0·62 mile), which would make only 0·0000033 per hundred feet, a co-efficient ten times less than that of Mr. Forbes. M. Bravais thinks that, in as far as concerns the Pyrenees, Mr. Forbes's results are much more favourable to the opinion of a decrease of horizontal intensity. Mr. Forbes had, in fact, found for the Pyrenees a diminution of 0·000053 per hundred English feet, which corresponds to 0·000054 for a kilomètre: in every case the decrease would be much more rapid in the Pyrenees than in the Alps.

The analysis that we have been making of the distribution of the magnetic forces upon the surface of the globe, indicates to us that this distribution, although presenting many local irregularities, is nevertheless subject to general laws, which are always recognised; we shall make this come out, further on, in a more explicit manner than we have hitherto done; but we must first dwell upon an essential point, which we have already indicated, and which is destined to throw great light upon the origin of terrestrial magnetism, namely, the variation that each of these elements constantly undergoes.

We have already spoken of the secular variations; but there exist besides, annual and diurnal variations. The diurnal variation consists in the continual change of direction and intensity that the force of terrestrial magnetism, in a given place, undergoes during the twenty-four hours which constitute a day; also it is manifested under the form of diurnal variation of declination, diurnal variation of inclination, and diurnal variation of intensity. If, occupying ourselves with the first only of these variations, we take the mean between the extreme positions that are assumed by the needle in the twenty-four hours, in respect to the terrestrial meridian of the place of observation, or, which comes to the

same thing, between its maximum and minimum of declination in the same day, a difference which constitutes the amplitude of the variation, we obtain the mean absolute declination of the day.* The annual variation is deduced from the comparison of these mean declinations of the day; with this view, they are grouped by months, and the difference is taken, that exists between the mean monthly *maxima* and *minima*, having care to take account of the secular variation that influences, in a different manner, the months of the commencement and those of the end of the year.

Finally, the secular variation itself is obtained by taking the mean of the mean diurnal or monthly variations of the year, and in deducting it from that of the preceding or following years, according as the needle tends to approach or to recede from the terrestrial meridian. Care must be taken not to confound the monthly variation with the mean amplitude of the diurnal variation of each month. Thus, if I take, for each month of the year, the mean of the amplitude of the declination that takes place each day, at a same hour, I can find great differences in this respect between the different months,—differences, which, on the contrary, may become very feeble or null, if I take the mean of the mean declinations of all the days of the month. Indeed the former result depends upon the size of the amplitude of the variation of the declination in a same day, whilst the latter depends only on the change that the needle is able to undergo in its mean absolute direction, from one day to the other, or rather from one month to the other,—a change which may be null or very feeble, even when there have been very great differences in the amplitude of the diurnal variation, between one day and the following.

What we have just said of declination is equally applicable to the diurnal, annual, and secular variations of the other two elements, inclination and intensity; but, as we shall see, the variations, especially, in as far as concerns intensity, are

* This mode of determination is not free from all objection. M. Aimé shows, by a series of observations, that the result to which it leads may differ much from that which is obtained by taking the mean of the observations made every hour during the twenty-four hours.

much less sensible, and consequently much more difficult of appreciation.

The discovery of the diurnal variations of the magnetised needle goes back to the year 1722; it was made by Graham; but it is only from the commencement of this century, especially within thirty or forty years, that these variations have been observed in several places with sufficient care for us to have been enabled to discover in them some law. If we consider the diurnal variation only in a general manner, the following is what we may say that it consists of: —

In the northern hemisphere the north pole of the declination needle travels from the east to the west, from a quarter past eight in the morning to a quarter past one in the afternoon; from the west to the east from a quarter past one in the afternoon until the evening.

In the southern hemisphere, the south pole of the declination needle travels from the east to the west, from a quarter past eight in the morning until a quarter past one in the afternoon, and from the west to the east from a quarter past one in the afternoon until the evening.

From this we see that the movements of the needle, in one of the hemispheres, are opposed to what they are in the other; so that, if an observer, setting out from Paris, advances toward the equator, the north point of his needle, so long as he shall be in our hemisphere, will each morning accomplish a movement towards the west, whilst, as soon as he shall have passed into the other, this same point will, each morning, suffer a movement towards the east. Now, it seems impossible that the change of western into eastern movement is made in a sudden manner. It has therefore been believed that between the zone in which the former of these movements is observed, and that in which the latter is brought about, there must necessarily exist a line, in which in the morning the north pole of the needle would travel neither to the east nor to the west, and would consequently remain stationary. Is this line the terrestrial equator or the magnetic equator? Of this we are as yet in ignorance. It has been clearly found that the amplitude of the diurnal variations was much

less in the places near to these lines; but the points have not yet been found in which it was completely null; it is probable, as we shall see, that no such line exists.

Returning to the diurnal variations in the northern hemisphere, if we follow them more closely, we find, as results from a very great number of observations, and in particular from those of M. Arago, that the needle, in order to return from its eastern excursion towards the west, is found there twice in the twenty-four hours; that it thus makes two complete oscillations, and suffers consequently two *maxima* and two *minima* declinations, in the following manner:—

1st. Setting out from 11 P. M., the north pole of the needle travels from the west towards the east, attains a *minimum* declination at a quarter past eight in the morning, and then retrogrades towards the west in order to attain its *maximum* declination at a quarter past one.

2nd. Setting out from a quarter past one, the needle travels anew towards the east, attains a second *minimum* between eight and nine in the evening, and then returns towards the west for a second *maximum* at 11 P. M. The greatest amplitude is that of the demi-oscillation, that is executed from eight o'clock in the morning to one in the afternoon; this is why we had indicated it as constituting, in a general manner, the diurnal variation.

The amplitude of the diurnal variations is not the same in the various places, nor is it the same in the different epochs of the year, in the same place. Thus, by means of observations made during fifteen years, from 1820 to 1834, Arago found that the amplitude of the diurnal variation was at a mean from 13 to 11 minutes during the months of March, April, May, June, July, August, September, and October*, and from eight to six during the months of November, December, January, and February; that the mean maximum of the diurnal variation takes place in April, and the mean minimum in December; and that the mean diurnal variation is comprised between three minutes and seventeen minutes, which are the two extreme values, the former in December, the latter in June.

* The months of March and October are those months in which the mean amplitude of variation is the least (11′ 22″ to 11′), the month of April is that in which it is greatest (13′ 20″).

The inclination has also a diurnal variation; but this variation, more feeble than that of the declination, does not go in general beyond three or four minutes. From the observations of M. Arago, there should be a maximum of inclination between eight and nine in the morning, a minimum after two and three o'clock after noon, a second maximum between eight and nine in the evening, and a minimum between eleven in the evening and midnight. The greatest amplitudes of the diurnal variations seem to take place after the equinoxes.

The intensity also suffers diurnal variations, independent of those of inclination, as results from the numerous observations of M. Arago, made and calculated with great care. M. Hansteen, who had also observed diurnal variations of intensity, estimates that they are only apparent, if we have a care to take account of the variation of the inclination.

However, it has been generally recognised that there exists a diurnal variation, not only for horizontal intensity,—that which depends at once on the variation of inclination and on that of absolute intensity,—but also for this latter intensity, which is designated under the name of *total intensity*.

Independently of the diurnal variations, M. Arago has proved, by taking the mean monthly variations, two *maxima* towards March and September, that is to say, towards the equinoxes, and two *minima* towards June and December, that is to say, towards the solstices; this result is in accordance with that which had been obtained by Cassini, who was the first who had remarked an annual variation; but, according to this philosopher, this variation consisted only in the fact that the declination diminishes from the vernal equinox to the summer solstice; and that, setting out from this period to the vernal equinox, namely, during the other nine months, the mean monthly declination increases, the needle regaining its course towards the west. M. Arago had found that observations, made by Gilpin, proved the existence in London, in 1800, of a periodic oscillation, similar to that discovered at Paris, in 1786, by Cassini.

Among all the observations upon the diurnal variations of the three magnetic elements, and the results of which are gene-

rally in accordance*, we will transcribe the following Table, which contains the resumé of the observations of three years (1843, 1844, and 1845), made with the greatest care by M. Lamont, at Munich. We find collected in it the diurnal variations of the three elements; the variations of declination and of inclination are expressed in minutes; that of the horizontal and total intensities in ten-thousandths of the entire value. As the variations present characteristics essentially different, acccording as the declination of the sun is northern or southern, M. Lamont divides the year into two halves, and distinguishes the variations of winter and those of summer.

Hours.	Declination.		Horizontal Intensity.		Inclination.		Total Intensity.	
	Summer.	Winter.	Summer.	Winter.	Summer.	Winter.	Summer.	Winter.
1 A. M.	2·22	0·76	13·65	5·04	0·08	0·29	8·03	2·57
2 „	2·05	0·98	12·98	4·58	0·16	0·36	7·73	2·43
4 „	1·80	1·49	12·02	5·93	0·23	0·14	7·21	3·15
6 „	0·52	1·47	9·99	6·77	0·50	0·00	6·08	3·59
7 „	0·00	1·37	7·27	6·70	0·97	0·01	4·51	3·58
8 „	0·05	0·97	3·23	5·14	1·56	0·25	2 26	2·70
9 „	1·33	1·19	0·29	2·56	1·92	0·60	0·33	1·26
10 „	3·73	2·39	0·00	0·46	1·97	0·92	0·00	0·04
11 „	6·47	3·98	1·87	0·00	1·66	1·07	1·17	0·00
Noon	8·70	5·28	5·47	1·80	1·23	0·92	3·47	1·24
1 P. M.	9·58	5·56	8·61	3·34	0.92	0·78	5·30	2·45
2 „	9·04	4·84	10·58	3 27	0·79	0·85	7·15	2·60
3 „	7·67	3·47	11·83	2·81	0·72	0·94	8·16	2·40
4 „	5·85	2·48	11·69	2·18	0·79	1·02	8·19	2·11
5 „	4·38	2·06	11·90	2·11	0·72	0·99	8·38	1·90
6 „	3·41	1·45	12·75	3·18	0·56	0·81	8·66	2·55
8 „	2·56	0·60	15·24	4·43	0·10	0·57	9·73	3·11
10 „	2·23	0·00	15·16	5·29	0·00	0·34	9·33	3·13
Midnight	2·14	0·44	14·15	5·40	1·10	0·27	8·65	2·84

* There exists, however, a remarkable exception to the general law of diurnal variations; it is that which has been observed by Mr. Gay at Valdivia, in Chili, upon the western coast of South America. In place of two movements, this way and that, in the twenty-four hours, Mr. Gay has constantly observed three: one in the morning to the east, a second in the middle of the day to the west, and the third in the evening again to the east; the hours of *maxima* and *minima* differ a little according to the seasons, but the triple movement always takes place, so that the phenomenon may be regarded as constant. The amplitude of the variations changes much from one day to the other; however, in accordance with a great number of observations, it may be estimated at 6′ 5″·2, the mean of six months; in summer this mean would be 7′ 1″·9, and in autumn 5′ 8″·4.

Each of the magnetic elements has two *maxima* and two *minima* of variations in twenty-four hours: —

	Maxima.		Minima.	
Declination - -	5 A.M.*	1 P.M.	8 A.M.	10 P.M.*
Inclination - -	10 „	4 „ *	7 „ *	11 „
Horizontal Intensity -	6 „ *	11 „	10 „	5 „ *
Total „ - -	7 „ *	10 „	2 „ *	10 „ *

The maxima and minima distinguished by an asterisk are less marked in summer.

The observations of M. Lamont have led him to recognise a very regular secular variation of declination, namely: —

1841–2 - - - - -	6′·48
1842–3 - - - - -	6 ·72
1843–4 - - - - -	6 ·85
1844–5 - - - - -	6 ·70

The secular variation of horizontal intensity is much less regular, as M. Hansteen has already remarked. M. Lamont's observations give for this variation: —

1842–3 - - - - -	0·0038
1843–4 - - - - -	0·0021
1844–5 - - - - -	0·0014

We have already seen that the secular variation of the inclination is not very regular; and that, after having been 5′ from 1778 to 1810, it is only about 3′·5 from 1820 to the present day.

An important remark of M. Lamont's is that, if we take account of the secular variation, and if we reduce the observations to what they would be if they were made at the same epoch, we do not find that the *annual* variation of the magnetic elements is very sensible. We have, in fact: —

	Declination.	Intensity.
January, February, March - -	16°40′·88	1·9348
April, May, June - - -	40 ·94	1·9351
July, August, September - -	40 ·81	1·9345
October, November, December - -	40 ·73	1·9348

Besides, as far as concerns the annual variation, we should

remark, that there is already a fundamental difference between the results of Arago and those of Cassini; since Arago recognises two *maxima* in the year, and that there is only one *maximum* according to Cassini; and that, moreover, the *maxima* and *minima* of Arago are very little decided. Would it not be possible that the annual variation may have diminished, and almost disappeared, since the secular variation has itself diminished in amplitude? It would be the same for the inclination, in which Arago had found an annual variation independently of the secular variation, and which consisted in this, that it had a *minimum* in April, and a *maximum* in August.

The amplitude of the diurnal variation would appear, according to the observations of M. Lamont, to be variable in a same place, according to the years. Thus, the difference between the declinations at 8 A.M. and at 1 P.M. would, for 1834–5, be 8′·25, and would go on increasing onwards till 1836–7, in which it would be 12′·9; setting out from which, it would go on gradually diminishing up to 1844–5, when it would not be more than 7′·41.

M. Lamont has confirmed this regular variation in the amplitude of the variations by consecutive diurnal observations up to the year 1855; and he has been led to recognise that the magnitude of the variations of declination has a decennial period, in such sort that it increases regularly during five years, and, in like manner, decreases during five other years. He finds that the epoch of most feeble variation of declination is 1843–4; and that of the greatest, 1848–9. Besides the maximum, already pointed out, of 1836–7, he finds another in 1817, by means of the observations of Colonel Beaufoy, and even another in 1786–7, by means of those of Cassini. The same decennial period is remarked in the variations of horizontal intensity; thus, in 1843, this intensity has a minimum, then a maximum in 1848, setting out from which, it again begins to decrease till 1853. Already, by comparing the observations of intensity made by M. Kreil, at Milan, in 1837–9, with his own more recent ones, M. Lamont had found that the variation

of this element, just like that of declination, has diminished since the period mentioned.

Independently of the regular variations, the magnetic elements are subject to irregular variations or disturbances, which are in general simultaneous in several different places, and themselves appear subject to certain general laws. In order to study these irregular movements, it is necessary to deduct from each observation the mean monthly value of the declination which corresponds to the same hour; what remains is the deviation of the needle from its regular march. M. Lamont has drawn out Tables, which present these deviations for more than 20,000 observations. The inspection of these shows that the irregular movements of the needle have a regular diurnal period; we see in these that the hours of *maximum* and *minimum* of these periods coincide with the hours of the secondary *maxima* and *minima* of our Table of Diurnal Variations, inserted above. M. Lamont deduces from it the remarkable consequence that the diurnal march, such as we observe it, is due to two different causes: we shall see further on that this remark of M. Lamont is in accordance with a similar remark of M. Bravais and of Major-Gen. Sabine, in connection with observations made in very different places. M. Kreil, who has made a particular study of magnetic disturbances, has thought he could remark in them a kind of annual periodicity; but a very great number of years of observations would be necessary, in order to demonstrate the actual existence of such a periodicity. Besides, we shall be returning to the irregular movements of the magnetised needle, when occupied with the aurora borealis, with the appearance of which they are intimately connected.

We have hitherto studied the magnetic variations only in the same place, regarding them merely in their relations with time. But the variations of the magnetic forces of the globe do not depend simply upon time; they depend also, as these forces themselves do, on the place of observation. This element of the question possesses an immense importance, by the light which it is able to throw upon the nature and origin of the forces in question; hence magnetic observa-

tions have been multiplied upon very different points of the surface of the globe, and endeavours have been made to render the observations made on these various stations as simultaneous as possible. We have already pointed out, in this respect, the labours of Major-Gen. Sabine, and the observations that are making, under his direction, in four points of the globe, both very different both in respect to each other, as well as to Greenwich and other European places, with instructions perfectly similar in all these observatories. These four stations are Toronto, St. Helena, the Cape of Good Hope, and Hobarton. Let us also note the simultaneous observations that have been made for a long time with instruments perfectly similar, in a very great number of observatories, by Gauss and several philosophers, who were associated, and who agreed that there should be in the year six periods of observations, each of a duration of twenty-four hours; in addition to these, two supplementary periods, during each of which observations should be made every five minutes. Finally, MM. Lottin and Bravais, in the northern regions, and M. Aimé at Algiers, have likewise, by their observations, enlightened the subject with the influence of localities upon the laws of the variations of the magnetic elements.

Major-Gen. Sabine has established a succession of comparisons between the divers variations, in the four stations that we have indicated.* He first traced the curves, which indicate the series of mean positions of the declination needle in the twenty-four hours, or the mean diurnal variations of this declination for Toronto, Hobarton, St. Helena, and the Cape, the observations being made every hour during five years. The curve for Toronto is exactly contrary to, and at the same time symmetrical, with the exception of a few irre-

* We think it useful to give here the geographical position and the magnetic characters of the four stations, to which we add that of Greenwich:—

	Latitude.	Greenwich Longitude.	Mean Dec.	Mean. Inc.
Toronto - -	43° 40′ N.	77° 5′ W.	1° 25′ W.	75° 15′ N.
Hobarton - -	42 52 S.	147 27 E.	9 58 E.	70 34 S.
St. Helena - -	15 56 S.	5 40 W.	23 36 W.	21 40 S.
Cape of Good Hope	33 56 S.	18 30 E.	29 5 W.	53 15 S.
Greenwich - -	51 31 N.	- - -	22 51 18″ W.(1847)	69 0 N.

gularities, with that for Hobarton. Thus, at Toronto, the north pole travels towards the east from 1 P. M. till 10 P. M.; from 10 P. M. till 2 A. M. it returns towards the west; it then renews its movement towards the east until 8 A. M., the moment of its maximum of eastern declination; it then turns in a continuous manner towards the west until 1 P. M., the epoch of its maximum of western declination. At Hobarton, the north pole marches to the west from 2 P. M. till 11 P. M.; from 11 P. M. till 3 A. M. it returns towards the east; then it regains its movement towards the west until 9 A. M., the moment of its maximum of western declination; it recovers again a continuous movement towards the east until 2 P. M., the moment of its maximum of eastern declination. It must be noticed that the curve is very decided from four to five in the morning, until six or seven in the evening, equally in both stations, although in an inverse direction. We may also observe that the movements at Toronto, still being identical, but of contrary signs to those of Hobarton, are habitually one hour in advance of these latter.

The curve of St. Helena and that of the Cape of Good Hope greatly resemble each other; they are both of them divided into two branches, corresponding to two periods,—one from May to September inclusively, the other from October to February inclusively; the months of March and April not having any very determined character. In the first period, the dominant variation is eastern, in the second it is western; if we follow the march of the needle at St. Helena in the first period, we find that, setting out from 11 P. M., the north pole of the needle deviates very slowly to the east until 4 A. M., an epoch setting out from which the deviation rapidly increases until 7 A. M., when it attains its maximum; setting out from this moment, the needle retrogrades promptly towards the west until 10 A. M.; then it suffers only slight oscillations until 11 P. M. It is between 5 and 6 P. M. that it attains its maximum of western declination, which is much less decided than that of eastern declination. The march of the needle at the Cape follows almost the same phases, only it commences to retrograde towards the

west between 11 A. M. and noon, instead of 10 A. M., and it is at this moment that its maximum of western deviation takes place; it then oscillates around its mean position until 11 P. M.; it only suffers a second maximum of eastern deviation between 3 and 4 P. M., but it is not very decided. In the second period, it is at 10 P. M. equally in both stations that the needle commences its movement towards the west, which attains its maximum at 8 A. M. for St. Helena, between 9 and 10 A. M. for the Cape; setting out from this moment, the needle moves itself rapidly towards the east, and attains its maximum of eastern deviation at noon for St. Helena, and between 1 and 2 P. M. for the Cape; it then retrogrades towards the west until 5 and from 6 to 7 P. M., epochs setting out from which it no longer suffers any very sensible movement until 10 P. M.

We see, by these results, that St. Helena participates, during one half of the year, with regard to the march of the diurnal variation of the needle, in the characteristics of the stations of the northern hemisphere, and during the other half in the characteristics of the stations of the southern hemisphere. The opposite movements which simultaneously take place each day of the year, on the same meridian in the two hemispheres, do not neutralise each other, as one might have believed, so as to leave the needle stationary; but, on the contrary, the diurnal variation at St. Helena possesses at the same time the characteristics of that which takes place in both hemispheres; only, during one half of the year, it is the characteristic of the variation of the northern hemisphere, during the other half, it is the characteristic of the variation of the southern hemisphere, that it presents. In the intermediate months of March, April, September, and October, the diurnal variation participates more or less, according to the day, in the characteristics peculiar to both seasons; nevertheless, September may be considered as appertaining to the period of May to August, and October to the period of November to February, although they both present, between 5 and 7 A.M., some traces of characteristics opposed to that of their periods. With regard to March and April, they both equally manifest

in the morning hours a declination, first eastern, then western, which is a cause that they cannot be included either in one or the other period, since they have the characteristics of both. It is important to remark, that the two portions of the year in which the diurnal variation takes place in opposite directions in St. Helena, are not determined by the declination of the sun, relatively to the latitude of the place, but rather by this declination, relatively to the equator; for, in the former supposition, the declination of the sun becoming southern for St. Helena only in the first week in November, and consequently becoming northern again as early as in the first week of February, the two periods would be respectively three and nine months, instead of being equal, as they are. They are not, therefore, separated from each other by the moment in which the sun, in its passage to the meridian, is situated at the zenith of St. Helena, but rather by that in which it is at the zenith of the equatorial line. We shall see in the following Section the importance that is presented by this remark, in the explanation of the diurnal variations.

With regard to the Cape of Good Hope, the latitude of which is 33° 56′, and for which, consequently, the declination of the sun is northern all the year, there is not even a possibility of putting the question, with which we have just been occupied for St. Helena. It would seem that, for its diurnal magnetic variation, this station should obey the laws, which govern this variation in the southern hemisphere; nevertheless, it participates, in this respect, in the characteristics of the intertropical stations; and, as at St. Helena, the two periods are separated by the moment in which the sun passes to the equator, the declination taking place in the east when the sun is in the northern hemisphere, to the west when it is in the southern.

This anomaly, which is presented by the Cape of Good Hope, is the more striking, as, if we take in the northern hemisphere a station, situated at about the same distance from the equator as Algiers, whose latitude is 36°, we find, as follows from M. Aimé's observations, that, during the entire year, the needle arrives at the limit of its excursion to the east about

2 P.M. Now, if the movements of the needle were at the Cape the reverse of those of Algiers, the limit to the west ought to happen at a mean, throughout the year, about 8 A.M., and the limit to the east about 1 or 2 P.M.; whilst, as at St. Helena, there is an analogy with Algiers in the movements of the needle during the months comprised between the autumnal equinox and that of the spring, and an opposition only during the months comprised between the vernal and the autumn equinox. There is, therefore, in the special situation of the Cape of Good Hope, a peculiar cause, probably its isolation in the middle of the seas, which makes it participate, as far as concerns the magnetic variations, in the characteristics of intertropical stations. It further participates in them, in that the amplitude of the diurnal variations, which is there much less considerable, almost half less than it is at Algiers. However, it is equally at the Cape, as at Algiers, when the sun has the smallest elevation above the horizon—in January for Algiers and in July for the Cape—that the variations are the most feeble.

It follows, therefore, from the observations that we have just been recapitulating, and which have been made with the greatest care, that there does not exist, as Arago had believed, any line between the two hemispheres, in which the needle, during the whole year, does not march, either to the east or to the west, that is to say, remains stationary, suffering no diurnal variation; but there exist stations in which the diurnal variation, during half the year, is east, and during the other half west. There may exist, it is true, a line in which the mean annual variation of the declination is null; it is that which includes the points in which the western and eastern variation are equal in duration and in intensity. St. Helena is very nearly being one of these points; however, it appears that its mean curve comports itself as belonging slightly to the southern hemisphere; the line, in which the mean of the diurnal variations of the year should be null, would, therefore, pass to the north of St. Helena.

Although in general the diurnal variation increases in amplitude in proportion as places, whose latitude is more

elevated are in question, nevertheless, M. Bravais, by taking account of the disturbances which are very frequent in the northern regions, has found by the comparison of the magnitudes of the arc traversed simultaneously at Bassekop and at Gottingen, between 8 A.M. and 1 P.M., namely, during the moment of the day when the irregular perturbations are scarcely felt, that the western excursion of the needle of Bassekop is less than that of the needle of Gottingen, in the relation of about 5 to 6. But it is no longer the same for the disturbances, that increase considerably in extent in proportion as the pole is approached, where they are much more frequent. M. Bravais is also led to attribute the variations of the needle to two kinds of action, of a very different nature, which he names *wave*, and which he designates by the names of *polar wave* and *equatorial wave*. The former, of a variable intensity, decreases in proportion as we approach the equator, and evidently results from the forces, the focus of which is situated in high magnetic latitudes; the latter, constant, goes on, on the contrary, increasing from the poles towards the magnetic equator; and the origin of the forces by which it is generated is situated in the equatorial regions. We shall have occasion to speak again of this distinction in the following section. Returning, for the present, to the magnetic disturbances themselves, we should remark that Major-Gen. Sabine, by means of observations made at Toronto and Hobarton, had found for them some very curious and peculiar characteristics: 1st. The irregularity of their march, a great number of days elapsing without our being able to discover traces of it; 2nd. The considerable extent of the deviation from its normal position to which the needle is exposed during their continuance; 3rd. Their simultaneous existence, or nearly so, in all parts of the globe. By means of these characteristics, Major-Gen. Sabine was enabled to prove that among 22,376 hourly observations at Toronto there were 1650 of them disturbed, namely, in which there were disturbances; which establishes the relation of 1 to 13·6 between them. At Hobarton, among 21,436 hourly observations, there were 1479 of them disturbed, which gives the relation of 1 to 14·5.

What is remarkable is that, at these two stations, situated in different hemispheres, and almost in opposite points of the globe, the total number of disturbed observations is distributed among the respective years, in such a manner that, taking for a unit this number in 1845, we find that it is —

	At Toronto.	At Hobarton.
In 1844 - -	1·08	1·12
1843 - -	0·84	0·83.

To this agreement is joined the fact that the disturbed observations took place in the three years, for the most part, on the same days in both stations. Major-Gen. Sabine concluded, like M. Lamont and M. Bravais, from all the work to which he devoted himself upon this subject, that the phenomenon of diurnal variation must be considered necessarily as consisting of *two* periodical variations, superposed upon each other, having laws extremely dissimilar, and probably different immediate causes; and that moreover these two constituent elements of variation present very different relations, one in face of the other, in the different parts of the globe, and that it is only in regions nearer to the poles that the influence is felt, upon diurnal variation, of that one of the elements to which the disturbances are due.

A very interesting point which has also occupied Major-Gen. Sabine is the comparative determination for each of the four stations, Toronto, Hobarton, the Cape of Good Hope, and St. Helena, of the amplitude of the mean monthly variation of declination, for each of the twenty-four hours of an entire day. This determination results from five years of observations at Toronto and at the Cape, and from three at Hobarton and at St. Helena. A graphic Table indicates, by means of vertical lines of greater or less length, the amplitude of the monthly variation for each of the twenty-four hours, and small marks upon each of these lines designate the mean magnitude of the variation for each month. The mean declination of the whole year, namely, of all the months and all the hours, is marked by means of a horizontal line, which cuts all the lines in very different points; for there are some among these lines which are entirely

above, others entirely below, the horizontal. A dotted line passes through the middle of all the vertical lines; it is a broken line, which shows the mean annual variation of the declination at each of the twenty-four hours of the day. If we compare the mean declination of a certain month, at a certain hour in a certain year, with that of the same month at the same hour in another year, we find these two values uniform; which shows that the mean declination, which is obtained by dividing the sum of all the declinations by their number, has the same value, whatever be the year that is considered. We must only remark that the absolute declination changes from one year to the other, on account of the secular variation, which may thus be easily determined, and which is found comparatively feeble at these stations, except for St. Helena, where it is considerable, since it suffers an annual increase of about eight minutes to the west.

The examination of the graphic Tables, drawn out as we have just been indicating, shows, in a striking manner, the almost complete similarity, which exists between the variations of the four stations, as far as their amplitude is concerned, at the same hours. They increase, in general, more rapidly in the first and second hour that follow sunrise; and they do not, at any hour, pass beyond the amplitude which they acquire from 7 to 9 A. M., at least at Hobarton, at the Cape, and at St. Helena; at Toronto, the greatest amplitude of variation takes place from 6 to 8 A. M. In general, in all the stations, the variations are much more considerable during the hours of the day than during those of the night.

It is not only, as may be supposed, upon the diurnal variations of declination that the influence of the position of the place of observation causes itself to be felt. This influence is no less upon the variation of the other magnetic elements. It is also in the very valuable collection of Major-Gen. Sabine that we can find the numerous results, that enable us to establish, under its divers relations, a comparison between the different stations.*

* We have consigned to a final note; C, the most important numerical results relative to the magnetic elements of the principal stations, in which observations are at the present time being made.

We shall not terminate this section, without dwelling upon an interesting fact that comes out of the comparison of the magnetic observations of Toronto and Hobarton. These two stations have this very important peculiarity, that their magnetic movements are generally inverse, which follows from their almost symmetrical position in the two hemispheres. The following Table, in which are found consigned the value of the diurnal variation of each month for each of the two stations, makes this opposition come out well:—

	Hobarton. (lat. 42° 51′ S.)	Toronto. (lat. 43° 39′ N.)
January	11·66	6·51
February	11·80	6·40
March	9·50	8·50
April	7·26	9·52
May	4·56	10·34
June	3·70 winter	11·99
July	4·61	12·70 summer
August	5·89	12·68
September	8·24	9·72
October	11·01	7·52
November	12·05 summer	5·75
December	11·81	4·47 winter.

But the opposition no longer exists if, instead of the variation of declination, the variation of intensity is in question. Thus at Toronto, whilst the sun is in the southern hemisphere, the inclination is 0′·88 above, and the horizontal intensity 0′·0015 below their respective means; whilst, when the sun is in the northern hemisphere, it is 0′·9 below and 0′·0011 above. The sum of the differences of inclination corresponds with 0′007 of variation in the horizontal component of intensity, which leads us to conclude that the total intensity has its maximum in winter, and its minimum in summer. At Hobarton the inclination is 0′·89 below the mean when the sun is in the northern hemisphere, and 0′·85 above when it is in the southern; the horizontal component of intensity is likewise greater than the mean at Hobarton from the month of October to the month of February; so that we must conclude from this that the total intensity

is more considerable there at this period of the year. Thus, it is at the same epoch, namely, in the interval comprised between October and February, which is the winter for Toronto and the summer for Hobarton, and not at the opposed epochs, that the inclination and total intensity are at their maximum, whilst they are at their minimum, in the interval comprised between April and August, which is the summer for Toronto and the winter for Hobarton. It is therefore found that the part of the year in which the magnetic force is greatest, and the inclination needle the nearest to the vertical, in both hemispheres equally, corresponds to the epoch in which the earth is the least distant from the sun, and in which it moves most rapidly in its orbit. This result indicates the existence of a general influence upon the whole of the globe, having an annual period; and seems to designate the movement of the earth in its orbit as being able to lead toward an explanation of this periodical change. However, as far as the diurnal variations of declination are concerned, Toronto and Hobarton follow the general law. The amplitude of these variations is, for each of the stations, from about 12′ in the summer months (from August to October for Toronto, and from October to March for Hobarton), and from 4′ to 6′ in their respective winters, as follows from the above Table.

It would also appear that the position of the moon, in respect to the earth, is not without influence upon the movements of the magnetised needle. M. Plantamour, in a very complete work upon the variations of the divers magnetic elements at Geneva, during the years 1842 and 1843, had already pointed out this influence. After having shown by the comparison of the variations, that take place in a same day, from one hour of the day to the other, that the declination increases from 8 A. M., in which it is the most feeble, to 1 P. M., epoch of the maximum; and that there is, in the evening, a second minimum and a second maximum, M. Plantamour, passing on to the examination of the variations that take place at the same hour of the day, from one day to the other, had found that the declination, at the same

hour, goes on increasing for some days, then diminishing, until it arrives at a second minimum. The time, comprised between a maximum and the following minimum, is a little less than fourteen days; and it is the same as the interval comprised between a minimum and the following maximum. The mean difference between a maximum and a minimum is 3′·75. It seems natural to seek for the cause of these variations in the movement of the moon, which presents analogous periods.

M. Kreil and Major-Gen. Sabine have both equally thought they remarked the lunar influence upon the movement of the needle, but under another form. In order to account for this effect, they have arranged the twenty-four observations, made in a solar day, so that each of them was placed in a Table in the lunar hour, to which it was nearest.* In this manner the mean of the observations made at each lunar hour, will indicate the relative direction of the needle at each of the twenty-four lunar hours; that is to say, at 0 h., when the moon is at the upper meridian, at 12 h., when it is at the lower meridian, at 6 h. and at 18 h., when it is at 90° from the meridian; and at the intermediate hours, when it corresponds to an intermediate horary angle. Now, when we have done this, and have grouped together a certain number of lunations, so as to counterbalance, and consequently to diminish, the influence of the other disturbing causes, we find that the direction of the needle undergoes a regular and periodical change in the space of a lunar day; there are two epochs of maximum of deviation towards the east, and two of maximum of deviation towards the west, between two consecutive passages of the moon at the upper meridian of the station; the change of position is continued from one of the extreme deviations to the other. On account of the difference that exists between solar times and lunar times, the observations, grouped under a certain

* It is known that the hours reckoned in *lunar* time differ from those reckoned in *solar time*, in that there elapses at a mean twenty-four hours 40′ of solar time, between two consecutive passages of the moon to the meridian. The lunar hour is therefore a little greater than the solar hour, and the observations, made at regular intervals of solar time, do not correspond exactly to regular intervals of lunar hours.

lunar hour, finish by including all the successive solar hours; and consequently, when the mean is taken of a great number of observations, every variation, arising from the action of the sun, must be found to be compensated.

If we compare, in respect to lunar action, the three stations of Toronto, Hobarton, and St. Helena (the work has not been done for the Cape), we remark that, at Hobarton and St. Helena, both situated in the southern hemisphere, the western declinations are more considerable*; whilst, at Toronto, in the northern hemisphere, it is the eastern. There is another very marked feature of difference between Toronto and Hobarton with regard to the lunar hour at which the extreme eastern and western variations are produced; at Toronto, the eastern take place almost exactly at the moment of the passage of the moon on the upper and lower meridian; and the western, after the sixth and eighteenth lunar hours. At Hobarton, the western declinations take place about two hours after the passage of the moon, and the eastern two hours before the sixth and eighteenth lunar hour. These differences may doubtless give some notions as to the magnetic power of the moon; but, before being able to draw any conclusions, in this respect, it would be necessary to know the corresponding effects produced upon the other magnetic elements, the inclination and the intensity; but they have not yet been determined.

Major-Gen. Sabine remarks that, in the magnetic variation occasioned by the moon, no trace is found of the decennial period, discovered by Lamont, in all the variations that depend upon the sun; and which appears to be confirmed, by the whole of the observations.

The result of the analysis that we have been making of the observations relative to terrestrial magnetism — observations of which we have been able to give only an abridged idea, notwithstanding the space we have devoted to them, — is that in the midst of so great a diversity in the value of the

* It is always the movement of the north pole of the needle that is in question, as well in the southern as in the northern hemisphere.

numerous magnetic elements that we have been studying, we may nevertheless discover certain general laws to which these elements are subject. The fundamental principle is, that the magnetic elements are at once dependent on time, that is to say, on the period of the observation, and on space, that is to say, on the place of the observation. We have seen that in a same place the declination, inclination, and intensity undergo changes, either regular and periodical, or irregular. The former are at once *secular*, following a period, the limits of which are not yet known, for want of observations, sufficiently prolonged; *annual*, these are the least decided; and finally, *diurnal*, these are the most complex; for they vary in their magnitude, with the different months of the year, and even with the years; being, in this respect, subject to a decennial period. With regard to the irregular changes, they appear themselves to obey certain laws, both in respect to their epochs, as well as in respect to the places of their appearance; for a very remarkable thing is, that they show themselves, in a manner almost always simultaneous in the places of the globe, the most distant from each other, constituting what M. Humboldt calls *magnetic storms*.

The influence of the place of observation over the magnetic elements is likewise considerable; but it cannot be exactly estimated, except so long as account is taken of the time; since, without this, no comparison would be possible in this respect between the various points of the globe. The following is the manner in which this influence of place may be summed up.

1st. The declination does not appear to have been connected, either nearly or distantly, with the geographical position; the places in which the declination is null, namely, in which the direction of the magnetised needle coincides with the plane of the terrestrial meridian, appear to determine, by their position on the globe, three different lines, two of which especially are well marked, which have the general form of meridians, but are in no degree either regular or stable. One of these lines passed through Paris in 1663; it has since had a movement towards the west, which

appears to have been arrested; and it now passes through Philadelphia. With regard to the lines that pass through the points which, without having a null declination, have the same declination, and which have been named magnetic meridians, they are likewise very irregular, and do not form great circles of the sphere.

2nd. The inclination and the intensity appear in general to march together. These two elements have their least value in the equatorial regions; however, the notion of a magnetic equator, that is to say of a line, passing on the terrestrial sphere through all the points at the same time, where the inclination might be null, and the intensity might have its least value, does not appear to be able to be admitted, unless very approximatively. But setting out from the equatorial regions, in proportion as we advance toward the polar regions, in one hemisphere, as well as in the other, we see the intensity, as well as the inclination, increase in a sensible and very regular manner; although, however, they are far from being the same in the places situated on the same parallels. Notwithstanding this approximate uniformity in the march of the inclination and the intensity, it is not at the points where the inclination is at its maximum, namely at 90°, that the maximum of intensity is found.

3rd. The variations are not the same upon all the points of the globe; although, in general, they obey the same laws. Thus, the variations of declination are of contrary signs in the two hemispheres; there exist no places in which they are null; only in the points situated between the tropics, and even in some situated without them (such as the Cape of Good Hope), the direction of the variation is for about one half of the year the reverse of what it is during the other half. With regard to the amplitude of the variations of the divers magnetic elements, it increases, in general, with the absolute intensity of the magnetism itself, being more considerable in proportion as the polar regions are approached, setting out from the equator.

Hypotheses on the Causes of the Phenomena of Terrestrial Magnetism.

The detailed examination, that we have been making in the preceding section of the divers and numerous results, that have been already furnished by the magnetic observations, so multiplied upon the surface of the globe, enable us now to inquire into the causes to which they may be attributed.

A point that is well established, and has long since been so, by Gilbert, is that the forces, which act upon the magnetised needle, emanate directly from the terrestrial globe; the simple analysis of these forces and of their effects demonstrates it, the variation of inclination and intensity with the latitude itself, and with the height above the ground, the nature of the directive action, &c., are only compatible with the notion of a terrestrial magnetism, that is to say, of a cause having an origin in the earth. But what is this magnetism? Where does it reside? What is its form, its distribution, its origin? These are the questions that naturally present themselves.

Gilbert had thought that the earth is a magnet, and that it has consequently two magnetic poles, tolerably near to its terrestrial poles; after him Halley arrived at the belief that, in order to explain all the phenomena of terrestrial magnetism, it would be necessary to admit the existence, not of two, but of four poles. M. Hansteen, more recently, had arrived at the same conclusion, and had even assigned the place to these four poles. It would, under this hypothesis, be necessary to admit that the earth would be traversed by two magnets, crossing each other in its centre, and the axes of which would thus form together a certain angle. It is true that there exists in the earth a magnetic oxide of iron, endowed with polarity; M. de Humboldt has made some curious observations upon the polar magnetism of certain rocks, and even of a mountain. But, besides our being unable to admit that the earth contains a quantity of these magnetic rocks sufficiently great to constitute terrestrial magnetism, we could not comprehend to what would be due

the regular distribution which their magnetic polarity would assume. They cannot therefore play any other part than that of determining local anomalies in the general direction of the magnetised needle, or in the intensity of terrestrial magnetism.

Moreover, the hypothesis of magnetic poles in the interior of the earth had been subjected to calculation by M. Biot, who had found that, in order to include in this hypothesis all the observations, relative to terrestrial magnetism, it would be essentially necessary to assume that the two poles were very near to each other, and at a very small distance from the centre of the globe. But fresh observations, which have been made since M. Biot's calculation, that is to say, within forty years, are not compatible with the hypothesis of four equal and contrary poles, situated in any manner in the interior of our globe; this has been demonstrated by M. Pouillet, who, in basing upon this hypothesis a general formula, satisfied himself that he could not represent the results of observations, since especially there was no possibility of representing, with a sufficient approximation, the summary of the observed declinations, nor even of the declinations that appertain to the terrestrial equator or to any parallel whatever; and that this impossibility does not result even from the doubts that may exist upon the veritable track of the magnetic equator. Calculation shows that, if the magnetism of the earth were due to two equal and contrary magnetic poles, situated in any manner whatever, there ought to exist an exact symmetry of the declinations, at the extremities of a same line passing through the point, in which the magnetic axis traverses the equator; now, we see on the contrary upon the circumference of the equator a striking dis-symmetry; instead of two points in which the declination is null, we find three, and instead of having equal and opposed *maxima* of declination, it happens that one of these *maxima* surpasses the other by several degrees. It is therefore evidently impossible to explain the magnetic phenomena, by supposing that, for all points of the earth, the centres of action are the same.

Does the hypothesis of the four poles of Halley and M. Hansteen, satisfy better the exigencies of observations? We

think less so, seeing that the points, to which M. Hansteen has applied the denomination of poles, have not the characteristics of such; they are only, as Major-Gen. Sabine has shown, the points of the greatest magnetic intensity for two systems, which are distinguished from each other by the difference in the degree of secular variation, to which the phenomena appear to be subject in each of them. Besides, why only four poles and two magnets, when once we can divest ourselves of the natural idea of two poles, and of a single magnet? Let us further add, in opposition to the hypothesis of magnetic poles properly so called, situated in the interior of the globe, the impossibility of recognising the existence of powerful magnetic centres, more or less near to that of the earth, with the very probable existence, in this portion of the globe, of a very high temperature, which is incompatible with a decided magnetism.

Gauss's opinion, that the whole mass together of the globe is magnetic; and that there exist a great number of magnetic centres, appears to us infinitely more rational. Only M. Gauss is obliged to attribute to each portion of the globe a considerable mean magnetic power, namely to each mass of 4·4 cubic feet, the magnetic force of a magnetised bar, capable of supporting the weight of 17·2 oz. avoirdupois.

Mr. Barlow, after having demonstrated that, neither the presence of a single magnet, nor the arrangement of several magnets in the interior of the globe, could produce the phenomena of terrestrial magnetism, considers that, on the contrary, we may very well account for them by assuming, as Ampère did, electric currents, circulating around the terrestrial globe, in the direction very nearly from East to West. He has endeavoured to confirm this hypothesis by distributing upon the surface of a wooden globe a series of electric currents, arranged so as to produce, upon a magnetised needle, not subject to terrestrial influence, and placed in divers positions, the same kind of action that the earth imparts to it, in analogous positions; and experiment has confirmed his anticipations, at least in a general manner.

We are very disposed to believe that the forces, which

produce terrestrial magnetism, have their origin in the solidified portion, namely in the solid crust of the terrestrial globe, which does not prevent the points of application of their resultants being able to be in some sort in the interior of the globe, more or less near to its centre. Hence the idea of electric currents circulating in this solid envelope, and forming a solenoïd, more or less complicated, appears to us most natural. But, whence arise these currents, and what is the cause by which their direction is determined? We have rightly assumed, in order to explain atmospheric electricity, a production of electricity resulting from chemical actions, which take place in the interior of the terrestrial globe; but we could not comprehend how this development of electricity could give rise to currents, circulating from east to west. This direction must evidently be connected with the movement of rotation of the earth, which takes place from west to east, and consequently, it is only in the existence of induction currents, arising from a magnetic action exterior to the earth, but susceptible of being exercised upon it, that the confirmation may be found of the hypothesis of Ampère, adopted by Mr. Barlow.

Indeed, the inductive currents are connected more or less, according to their direction, with the direction of the movement of the induced body; and we know that, on causing a body, a spherical body for example, to rotate rapidly on its axis, under the influence of a magnetic pole, we are able to produce in it continuous induced currents. But where would the inducing body be, when the terrestrial sphere is in question? Evidently, it could only be found in the moon or in the sun. The moon plainly exercises an influence over the movements of the magnetised needle; but this influence is very feeble; and nothing enables us to discover traces of magnetism or of dynamic electricity in the moon, the mass of which besides is too small, in respect to the earth, for us to suppose that it can act upon it; it would much rather be the earth that might act upon the moon.*

* Indeed, setting out from the fact that the earth enjoys, from some cause or other, the properties of a large magnet more or less irregular, it is evident,

It is only in the sun that we may find a body exterior to the earth, capable of exercising upon it an inductive action. First, the sun appears to us to possess powerful electro-dynamic properties; for it is very probable that its light is due to energetic electric currents, which surround it; at least there does not exist an artificial light, which has more relation with solar light in all its properties than the electric light, such as that which plays between two carbon points, that communicate respectively with the two poles of a pile. Moreover, astronomers are disposed, by phenomena of another order, to admit a magnetic polarity in the sun. M. Lamont reminds us, that Bessel had already put forth the existence of a similar force, in order to explain the phenomena presented by Halley's comet, in which one part of the cometary matter appeared attracted by the sun, and the other repelled in an opposite direction. But while still attributing to the sun a strong magnetic power, and recognising that the earth in turning, under the influence of this power, must possess induced currents, there would be many points to examine before passing on this simple hypothesis to the rank of a satisfactory theory. It would be necessary to form an idea of the distribution in the sun of the magnetic forces, in order to be able to deduce from it the direction of the currents induced in the terrestrial globe; for, while still continuing to recognise, that the direction of the rotation of the induced body possesses the greater part of the influence in the direction of the currents, arising from this induction, the position of the inducing body has also a considerable influence. The movement of the earth in its orbit, and consequently its change of position in respect to the sun, each

by its rapid motion of rotation, it must induce in the moon, whose motion is much less, closed currents, more or less intense according to the conductibility of the materials of which our satellite is formed. It would be the action of these currents upon the needle that would explain the slight variations due to the influence of the moon. An interesting question to solve would be, knowing exactly the distribution of terrestrial magnetism upon our globe, to find out what ought to be, for the different phases of the moon, the direction of the currents induced upon its surface by the magnetism of the earth, and to see if this direction would accord with the lunar effect pointed out by various observers.

day of the year, — could this be reconciled with the very nearly constant direction of its magnetism?

With regard to the partial irregularity, that must be presented by the distribution of the induced currents around the earth, still obeying the general law of the direction from east to west, it might very well be explained by the differences in the degree of conductibility of the strata of the terrestrial crust. We very well conceive that our globe cannot be regarded as resembling a hollow sphere of a perfectly uniform thickness and nature; and that, consequently the induced currents cannot have in it a direction as regular as that, which they assume in such a sphere. We already know, by the researches of some geologists, and more particularly of M. Louis Necker, who was the first to point out this approximation, that there is a very marked connection between the lines of equal magnetic intensity, and the direction of certain chains of mountains, and consequently of certain upheavings. Might not the secular displacement of the direction of the magnetic forces of the globe be connected with an operation of gradual upheavings, which is being brought about beneath its surface; and which, by altering the distribution of the materials, of which its shell is composed, modify by this the direction of the induced currents? This would be, as it were, a canal, the direction of which would be gradually changed. What would give some probability to this hypothesis is, that the secular declination of the north pole of the magnetised needle to the west, has coincided with the movement of the polar ices, and in particular with the appearance of *icebergs*, near the coasts of Greenland; a movement and appearance, which geologists in general agree to attribute to a gradual raising of the bottom of the sea. With regard to the variations of inclination and intensity with the geographical position of the place of observation, they would be a rigorous consequence of the laws of electro-dynamics, when once we should have admitted that our globe is surrounded by a girdle of electric currents, all having a general direction from east to west, and the anomalies that are presented by this inclination and intensity, as well as by the declination,

would be a result of the necessary irregularities that exist on account of its non-homogeneity, in the mass traversed by the induced currents.

Moreover the magnetic influence of the sun is not a gratuitous hypothesis; we find a proof of it in the agreement that exists between the magnetic movements upon the surface of the earth, and the various positions of the sun, in respect to the places of observation. Endeavours had at first been made to explain this agreement by an indirect action of the sun; and in this respect some hypotheses had been proposed, which we are about to detail successively, both in order to show in what they are insufficient, as well as because, if they do not play the first part, they possess at least an important part in the explanation of certain phenomena of terrestrial magnetism.

The first of these explanations, which has been essentially developed by M. Aimé, consists in attributing the diurnal variations of the magnetic elements to thermo-electric currents, all emanating from the most heated point,—a point which, changing its place with the sun, must make the turn of the globe in twenty-four hours; so that, in each place of the earth, except upon the parallel, in which the centre of the action is, the direction and the force of the currents change throughout all the duration of the day. It must result from this, that the diurnal movements of declination are generally symmetrical on both sides of the equator; and the meridian, in which the temperature of the terrestrial crust is most heated, being very nearly that of 2 P. M., it is towards the place in which the equator is cut by this meridian that we must place the centre, upon which the thermo-electric currents abut. The observations made in the two hemispheres are sufficiently in accordance with this hypothesis; but it has against it, independently of a general objection, what is common to all the explanations, that are associated with an indirect action of the sun, the small probability of the existence of thermo-electric currents upon the surface of the earth, either on account of the imperfect conductibility of this surface, or on account of the enormous

proportion of water that it presents; now, we have seen that liquids are not susceptible of thermo-electricity.*

The second explanation, founded upon an indirect action of the sun, consists in assuming the existence of electric currents, travelling on each hemisphere from the poles to the equator; these currents would be the consequence of the continual reunion that must take place between the positive electricity which, escaping with the vapour of the sea water, from the equatorial regions toward the upper regions of the atmosphere, goes thence toward the polar regions, and the negative, which has remained in the ground. I have endeavoured to show, in developing this explanation, that the direction of the currents is in accordance with that of the variations, in which the *maxima* and *minima* correspond, for each locality, with the epochs of the day and year in which, by the effect of the position of the sun, the temperature is the highest, and consequently the evaporation the most powerful. We shall return to this explanation, which, if it is, as we are about to see, insufficient of itself to account for the regular variations, should very probably be admitted, in order to explain a part of the phenomena in question, and in particular the disturbances; for it is certain that atmospheric or terrestrial electricity, which we have seen to play so great a part in meteorological phenomena, must exercise an action over the movements of the magnetised needle. But the regularity with which, during the times of a storm, and during the most violent tempests, as well as during the most calm weather, the magnetised needle most frequently accomplishes its oscillation, appears little compatible with an explanation which would make this oscillation simply to depend upon this electricity, so variable in its manifestations.

The third explanation is that of Faraday, who attributes the magnetic variations to the magnetic properties of the oxygen of the atmosphere,—properties which follow, in their

* The influence of the temperature of the surface of the globe upon the phenomena of terrestrial magnetism had already been pointed out by Mr. Hansteen, who had made the observation that the temperature in the neighbourhood of three of his four magnetic poles is much lower than in other countries situated under the same latitude.

degrees of force, the variations of temperature, in such sort that heating reduces them, and that cooling exalts them. Following the course of the sun in its calorific effects upon the atmosphere, Mr. Faraday succeeds in showing that the divers variations which the magnetised needle undergoes, arise from different magnetic states of the atmosphere, corresponding to its divers degrees of temperature; the influence of the hours of the day and of the seasons are thus found to be connected with variations of temperature, which result from it to the atmosphere. But we shall make to this explanation, besides the general objection, that we are about to present, the particular objection that we have made to the preceding, founded upon the difficulty of making the magnetic movements, which are so regular in their period, to depend upon an action, the intensity of which must be as variable as is the heating of the oxygen of the atmosphere by the effect of the sun.

The general objection, that we can make to all these explanations, independently of the difficulty of reconciling them with the regularity of the movements of the magnetised needle is, that the epoch of the variations, as Major-Gen. Sabine has very well demonstrated, does not depend upon the position of the sun, relatively to each place of observation, which must necessarily be the case, if the action of the sun is an indirect action arising from its calorific effect, but depends upon its absolute position, that is to say, upon its presence in one or other hemisphere; such that, for example, the diurnal variation changes in direction at the same time at St. Helena and at the Cape of Good Hope, although their latitude is very different; and the change takes place, for the two stations, even when both are in the southern hemisphere, at the moment when the sun crosses the equator, that is to say, at the two equinoxes only; and not at the moment when it crosses the parallels upon which they are situated.

It is therefore, we have said, in the direct action of the sun that we must seek for the explanation of the ordinary and periodic variations of the magnetic elements. Father A. Secchi has just demonstrated it by a remarkable analysis

which he has made of these variations and of their relations with the positions of the sun.

First, occupying himself with the diurnal and annual variations of declination, Father Secchi sums up the results of the numerous observations made upon these variations into certain principles, which we shall reproduce the more willingly, as they give an idea, at once exact and general, of this order of phenomena, whatever, in other respects, may be the theory that is adopted, in order to explain them.

1st. The diurnal variations of the magnetised needle follow in their course the time of the place of observation.

2nd. The pole of the needle that is found nearest to the sun (the south pole in our hemisphere) executes a double diurnal excursion in the following manner: — it is found at a maximum of western excursion four or five hours before the sun passes the meridian of the place; thence it marches toward the east with an increasing velocity, the maximum of which is presented toward the passage of the sun by the magnetic meridian; and it attains the limit of its eastern excursion, one or two hours after this passage. When the sun descends, in order to set, the needle returns back; and when the sun passes to the lower meridian, the same oscillation is repeated during the night, but with less amplitude. The hour limits of these changes vary with the seasons; generally they advance in summer, and are retarded in winter. All the variations are the same in both hemispheres, provided we change the name of the pole, whose march we are following. As the points of inflection of the diurnal curve depend on the passage of the sun through the magnetic meridian, if two places, situated in the northern hemisphere, have opposite declinations, the former to the east, the latter to the west, the phases of the latter will be retarded in respect to those of the former. If the places under consideration are not in the same hemisphere, we must take account at once of their declination, and of the opposition, that results in their magnetic movements, from the fact that they are in different hemispheres.

3rd. The diurnal excursion of the needle is the sum of

the two separate excursions, the former of which depends upon the hourly angle, and the latter on the declination of the sun. These two oscillations, by superposing in a variable manner, produce by their interferences all the phenomena of ordinary diurnal and annual variation. This may be proved, by means of the observations made at Toronto, Hobarton, St. Helena, and the Cape of Good Hope, which shows that the position of the magnetised needle at any instant depends upon the situation of the sun, relatively to the meridian of the place, and relatively to the equator. The effect of one of these causes may be eliminated, so that the second alone remains. In order to obtain the diurnal period alone, we have merely to take the mean of all the observations made during a year, at each of the hours of the day; and if we construct graphically a curve, by taking the hours for abscissæ, and the means of the declination thus obtained for ordinates, we obtain a curve, that represents the diurnal oscillation, which the needle would execute, if the declination of the sun were constant. If we take these means for each month only, we then have a curve of the monthly hourly means, that passes sometimes above, at other times below the former, which is that of the annual hourly means. In order to appreciate the effect of the declination of the sun, we have only to deduct the ordinates of the mean annual curve from the ordinates of the mean monthly curve; we thus obtain a new curve, representing for each month, the effect of the displacement of the sun. We notice that these monthly curves are of a form, similar to that of the annual curves, that they are opposed for the months of opposite declination, and that, for the equinoctial months, they are not very well defined, so that we see the part of the month predominate in them, that participates in the greatest distance from the equinox; this is particularly evident for the month of September, for which the change seems to take place on the very day of the passage of the sun on the equator. The march of the curve distinctly indicates that the magnitude of the excursion depends, both upon the declination of the sun and upon the absolute

magnetic force at the place of observation.* Thus the excursions are less at St. Helena than at the Cape; less at the Cape than at Hobarton; less at Hobarton than at Toronto. The sign of the monthly curves depends neither upon the geographical latitude nor upon the passage of the sun to the zenith of the place; Major-Gen. Sabine had already directed attention to this, as far as St. Helena is concerned. The moments, to which these maxima of excursion correspond in each station, evidently depend upon the passage of the sun to the magnetic meridian; however, the magnitude of the excursions is not in correspondence with the seasons of the place, but with the absolute position of the sun in respect of the earth; we must not forget that the question here is not of the amplitude of the diurnal variations, but of the monthly. Thus the greatest monthly excursion at Hobarton and at the Cape, takes place in the month of August, which is a winter month; and this greatest excursion takes place at Toronto in the same month, that is to say, in summer. At St. Helena, it is not produced when the sun is at the zenith, but rather when it is most removed from it, namely, in the months of June, July and August. When we desire to eliminate from the monthly curves the effect of solar declination, we have merely to add in couples the months, in which the sun has an opposite declination, and we then recognise the existence of a semi-diurnal period, which we have already proved; so that we may regard it as certain, that the needle is constantly subjected to a period of diurnal oscillation, and to another semi-diurnal period; this latter appears to depend rather upon the geographical latitude than upon the magnetic latitude.

Father Secchi, in summing up, thinks he is able to conclude from all the phases, which the variation of declination undergoes, that *the sun acts upon the magnetised needle as if it were itself a large magnet, placed at a great distance from the earth, and having its poles of the same name as those of the*

* This result of observation is very favourable to the theory, which makes the absolute force as well as the variation, that it undergoes in its direction and in its intensity, to depend upon the action of the sun.

earth, turned to the same side of the heavens. Only, in order to recognise the accuracy of these laws, it is necessary to have regard to the inverse actions, which the needle undergoes on the part of the sun in the twenty-four hours, by the effect of the rotation of the earth, the front of the needle that faces the sun, being different at noon and at midnight, and the earth being interposed at the second epoch. We shall return in a moment to the manner, in which the action of the sun upon the needle must be regarded; but we must first show that the other variations of the magnetic elements, as well as the declination, enter into the same law.

The variations of horizontal force, determined by the bifilar magnetometer, and those of the vertical force, compared at St. Helena, at the Cape, at Toronto, and at Hobarton, lead Father Secchi to this general solution, namely, that the horizontal component and the vertical component may be resolved into diurnal and semi-diurnal periods, which depend upon the declination of the sun and on the geographical latitude. With regard to the inclination, its phases are analogous to those of the declination, but with an advance of three hours, and the *maxima* of the horizontal force correspond in general with the *minima* of inclination, which should be the case. The total force is subject at Toronto to two periods, the maximum and principal minimum of which are at 5 in the afternoon, and at 3 or 4 in the morning, and the minimum and principal maximum at 6 or 8, and at 10 or 11 in the morning. At Hobarton, the secondary period is manifested less completely in certain months than in others; and at the Cape the variations of the total force are almost complementary to those of declination.*

* In order to explain well the whole of the periods of oscillation, which the needle undergoes, we must conceive with Major-Gen. Sabine a magnetised needle suspended no longer by an axis, but by a single point, namely, its centre of gravity, and which would be free to obey all the simultaneous impulses, whatever their direction may be. Major-Gen. Sabine has constructed the curves that a needle would trace out under these conditions by taking two rectangular co-ordinate axes, the origin of which represents the mean diurnal position of the needle, and by taking for each hour the declinations for abscissæ and the inclinations for ordinates. We then recognise that the oscillation of the needle has always in the twenty-four hours a double period, the one diurnal, the other nocturnal, the extent of which varies notably, according to the seasons. The diurnal

We may refer here also to the important observation of Major-Gen. Sabine, that at Toronto and Hobarton the total force is at its maximum in the same months, namely, December and January, although they correspond to opposite seasons in the two hemispheres; whence Father Secchi concludes that the disturbing solar force is greater when the distance of the sun is smaller and that it does not depend upon the seasons.

It seems to me more natural to conclude from this, that it is not only the disturbing force, but the absolute force itself of terrestrial magnetism, which depends upon the sun; the more so as Father Secchi clearly admits that it is not upon the needle directly, that the sun acts, but that it acts upon it indirectly, by modifying the magnetism of the globe. Now, if the action of the sun is the origin of the magnetic properties of the earth, either by a direct effect of magnetisation, or which is more probable, by the production of induction currents having the general direction of E. to W., it is easy to conceive that the changes of the relative position of the sun and the earth, either diurnal or annual, must bring about modifications in the directions, the intensity and the distribution of these currents. In particular, the difference that exists between the nocturnal and diurnal periods, would be a result of the interposition of the earth between the sun and the place in which the needle is—an interposition, which must necessarily modify the induced currents; there cannot be any identity in this respect between two points, situated, it is true, at the extremities of the same diameter of a sphere, but one of which is turned toward the inducing body, whilst between this body and the other, the whole mass of the sphere is found to be interposed. There would be a great interest in studying, both theoretically and experimen-

period, very developed in summer, is restricted in winter; whilst the nocturnal period, scarcely marked in summer, extends notably in winter. A remarkable character of all the simple periods is that the maximum and minimum are produced at about six hours apart. We see that the needle loses its greatest velocity at the moment, when the sun passes to the magnetic meridian, and that the movements of inclination are complementary, at three hours' distance, to those of declination.

tally, what ought to be the distribution of induced currents upon a conducting sphere, to which a rapid rotatory motion might be imparted, under the influence of a powerful inducing magnet, in endeavouring to determine the electro-dynamic state of each of the points of the sphere at the same instant, which would enable us to deduce from it, the electro-dynamic state of the same point in its successive positions, during a rotation of the sphere.*

As we have already remarked, the results that might be obtained under the hypothesis of an homogeneous conducting sphere, would be applicable only in a very general manner to the case of the earth, since this perfect homogeneity and conductibility do not exist in it; but it is upon the phenomena of absolute direction and intensity, that this difference between the real and the hypothetical case would be made especially sensible; their variations would be much less influenced, as may be easily conceived, except, however, the secular variations which would find their explanation in the modifications that the constitution itself of the globe undergoes. Similar modifications should, in fact, bring about changes in the direction and intensity of the induced currents; but these changes can only be very slow, as are the modifications which give rise to them; and consequently cannot have any sensible influence upon the diurnal and even the monthly variations.

We have hitherto supposed the sun motionless; and, it is in the motion alone of the earth, that we have sought for the cause of induction. Now, the sun has a motion around its axis; and this motion might modify its inductive action, more or less according to the manner, in which the magnetic forces, that emanate from it, are directed. However, it would not appear that this influence could have a very sensible effect. A circumstance that appears to have a more decided one, is the state of the surface of the solar globe. A very striking coincidence has been remarked between the augmentation of the disturbances of the needle and that of the

* It would be probably more easy a matter to obtain this determination by causing the magnet, rather than the sphere, to move.

spots of the sun; it is in the years, in which the spots have been least numerous, as 1833 and 1843, that the smallest number of magnetic disturbances have been observed: and in those of 1837–8, and 1847-8, in which they have been most numerous, that there have been most disturbances. But, what is most remarkable in the coincidence, that we have just pointed out, is the existence of a decennial period of the spots of the sun, which would coincide with the decennial period, proved by M. Lamont, in the amplitude of the diurnal variations; so that the years, in which there would be the greatest number of spots would likewise be those in which the amplitude of the variations would be the most considerable. M. Arago has likewise verified this coincidence.

We have said above that while still recognising that the direct action of the sun is the principal cause of the variations of the magnetic elements, we do not completely exclude its indirect action, such as it is exercised in particular by the production of the electric currents, that result from the reunion of the positive electricity, which the vapours that rise from the sea carry off, with the negative, that remains in the ground. This action is particularly sensible upon the declination needle, the movements of which follow a period analogous in part with that of temperature and of the other diurnal and annual meteorological changes. But it is null upon the variation of the horizontal and vertical components, and consequently upon the variation of the inclination and the intensity, which are manifested at different hours to those of the changes of temperature, and which have evidently another origin. This origin is in fact the direct action of the sun, which depends simply upon its position, in respect to the place of observation,—an action, which is manifested upon the variation of all the elements, and consequently upon that of declination, but which does not prevent that this latter may arise also, and at the same time, from the influence, that we have just been pointing out. The currents, generated by the reunion of the positive electricity with which the atmosphere is charged, with the negative, that has remained in the ground, must travel in each hemisphere from the polar

to the equatorial regions, and must consequently contribute to deviate the declination needle to the west in the northern hemisphere, to the east in the southern hemisphere. More concentrated near the poles, these currents must exercise there a more powerful action than in the points nearest to the equator; and their effect as well as their intensity must be more or less decided, which latter is itself variable with the meteorological circumstances, and consequently with the hours of the day. Their effect, which is sometimes added, and is sometimes contrary to that which results from the direct action of the sun, being therefore very variable, it hence follows that, although they obey a general and constant law, the diurnal variations of the magnetised needle are not for two days in the year exactly similar with regard to their amplitude, which would be difficult to explain, were the direct action of the sun the sole efficient cause of these variations. A very striking proof of the part played by these currents in the production of this phenomenon is found in the remark of M. Reslhuber who, on submitting the magnitude of the diurnal change of declination from 1842 to 1850 inclusive to the method of calculation commonly employed for periodical phenomena, succeeded, by means of numerous observations made at the observatory of Kreusmunster, in establishing that *the magnitude of the diurnal variation of declination during all the months of the year, marches parallel with the changes of the humidity of the air; it is smallest at the period of the greatest humidity, and greatest at the minimum of humidity.* This approximation between the amplitude of the variation of the inclination and the greater or less degree of humidity of the air, can arise only from the fact that the positive electricity which is in the atmosphere being able to unite more easily with the negative of the ground, as the air is moister, the currents directed from the pole to the equator, and consequently the deviations of the magnetised needle, which they bring about, are more feeble as a greater proportion of the two electricities is neutralised in a direct manner, and consequently as the air is more moist.

But it is especially in the production of disturbances in the needle, that the action of the currents in question makes its influence to be felt. It is these probably which constitute that polar wave, of which M. Bravais speaks, which acts concurrently with the equatorial wave, namely, with the influence that seems to arise from the equator, and which would itself be the result of the direct action of the sun. This origin of the polar wave would explain why the disturbances are more decided and more frequent, in proportion as the stations, in which the observations are made, are nearer to the poles. It would be less easy of reconciliation, it is true, with the very remarkable fact of the simultaneity of the disturbances generally observed in the places of the earth the most distant from each other, although we may however conceive a very complete oneness, in respect to their electric state, between all the parts of the terrestrial globe, when once it is recognised that this globe is a very good conductor. Moreover, the phenomenon of magnetic disturbances being intimately connected with that which must form the particular subject of our study in the following section, we shall postpone to that section all that we should have to say in addition, in respect to its origin.

Natural phenomena connected with terrestrial magnetism — Auroræ boreales.

The seat of terrestrial magnetism being in the earth itself, it seems that the phenomena, which take place at its surface or in its interior, should modify this magnetism or be modified by it. Hitherto, however, this order of relations has not been established in a very positive manner; it is, however, probable that the variations, which magnetic declination, inclination, and intensity have undergone, since they have been observed, should have depended upon the changes that have happened to the surface of the globe, such as the displacement of polar ice, or the modification undergone by the lower strata of the earth, such as upheavings, subsidings, &c. But these changes and modi-

fications, take place generally in so slow and so continuous a manner, that it is difficult to satisfy oneself if there exists any connexion between them and the movements of the magnetised needle. However, it has been remarked, on many occasions, that the magnetised needle is affected by earthquakes. Thus M. Arago observed, on Feb. 19. 1822, an extraordinary agitation in the needle of diurnal variations of the observatory; and there was at the same moment a strong earthquake in Auvergne, at Lyon, and in Switzerland. Mr. Gay likewise observed in Valdivia, on the western coast of South America, a very remarkable disturbance in the magnetised needle at the period of a terrible earthquake which took place in those latitudes in February, 1836.

But, among all natural phenomena, there is one whose connexion with terrestrial magnetism is so well established that we have, in the movement which the magnetised needle suffers, a proof of its presence. This phenomenon is that of the aurora borealis, or rather the polar aurora; for there are auroræ australes as well as auroræ boreales. The following is the description that M. de Humboldt gives in *Cosmos*, from which I have borrowed it, on account of the remarkable manner with which the principal details of the appearance of the phenomenon are set forth in it, so as to make its essential points come out.

"An aurora borealis is always preceded by the formation in the horizon of a sort of nebulous veil, which slowly ascends to a height of 4°, 6°, 8°, and even to 10°. It is towards the magnetic meridian of the place that the sky, at first pure, commences to get brownish. Through this obscure segment, the colour of which passes from brown to violet, the stars are seen, as through a thick fog. A wider arc, but one of brilliant light, at first white, then yellow, bounds the dark segment. Sometimes the luminous arc appears agitated for entire hours by a sort of effervescence, and by a continual change of form before the rising of the rays and columns of light, which ascend as far as to the zenith. The more intense the emission is of the polar light,

the more vivid are its colours, which from violet and bluish white pass through all the intermediate shades to green and purple red. Sometimes the columns of light appear to come out of the brilliant arc, mingled with blackish rays, similar to a thick smoke; sometimes they rise simultaneously in different points of the horizon; they unite themselves into a sea of flames, the magnificence of which no painting could express; for, at each instant, rapid undulations cause their form and brilliancy to vary. Motion appears to increase the visibility of the phenomenon. Around the point in the heaven, which corresponds to the direction of the dipping-needle produced, the rays appear to assemble together and to form the boreal corona. It is rare that the appearance is so complete, and is prolonged to the formation of the corona, but, when the latter appears, it always announces the end of the phenomenon. The rays then become more rare, shorter, and less vividly coloured. Shortly nothing further is seen on the celestial vault than wide, motionless, nebulous spots, pale or of an ashy colour; they have already disappeared, when the traces of the dark segment, whence the appearance originated, are still remaining on the horizon."

The connexion that appears to exist between the polar light and the appearance of a certain species of clouds is confirmed by all observers; all have affirmed that *the polar light emitted its most vivid rays when the high regions of the air contained heaps of cirra-stratus of sufficient tenuity and lightness to cause a corona to arise around the light.* Sometimes these clouds are grouped and arranged almost like the rays of an aurora borealis; they then appear to disturb the magnetised needle.* After a brilliant aurora borealis we have been able to recognise on the following morning trains of clouds, which, during the night, had appeared as so many luminous rays.

The absolute height of auroræ borcales has been estimated in a very different manner by observers. It has long been

* Father Secchi has remarked that magnetic disturbances are manifested at Rome, whilst the sky is veiled with clouds that are slightly phosphorescent, which at night present the appearance of feeble auroræ borealcs.

thought that we might determine it by regarding, from two places very distant from each other, the same part of the aurora, the corona for example; but we had started from a very inaccurate basis, namely that the two observers actually had their eyes directed to the same point at the same time, whilst it is now well proved that the corona is an effect of perspective, due to the apparent convergence of the parallel rays, situated in the magnetic meridian; so that each sees his aurora borealis, as each sees his own rainbow. The aspect of the phenomenon depends also upon the position of the observers. The seat of the aurora borealis is in the upper regions of the atmosphere; sometimes even it appears that it is produced in the less elevated regions, in which the clouds are formed. This at least is what follows from some observations, especially from those of Captain Franklin, who saw an aurora borealis, the light of which appeared to him to illuminate the lower surface of a stratum of clouds; whilst some 25 miles further on, Mr. Kendal, who had watched the whole of the night without losing sight of the sky for a single moment, did not perceive any trace of light. Captain Parry saw an aurora borealis display itself against the side of a mountain; and we are assured that a luminous circle has been sometimes perceived upon the surface itself of the sea, around the magnetic pole. Lieut. Hood and Dr. Richardson being placed at a distance of about 45 miles from each other, in order to make simultaneous observations, whence they might deduce the parallax of the phenomenon, and consequently its height, were led to recognise that the aurora borealis had not a greater elevation than 5 miles. Finally, M. Liais, having had the opportunity of applying a method, which he has devised for measuring the height of auroræ boreales, to an aurora seen at Cherbourg on Oct. 31. 1853, found that the arc of the aurora was about $2\frac{1}{2}$ miles above the ground, at its lower edge.*

* M. Liais's method consists in measuring the times t and t' that an arc of the aurora requires in order to traverse the same angle, following its radius to the zenith and to the horizon; admitting that all the parts of a same arc move with the same velocity, we have $h\left(\frac{t'^2}{t^2}-1\right)=2r$, h being the height

Mairan and Dalton had thought that the aurora borealis was a cosmical, and not an atmospheric phenomenon. But M. Biot, who had himself had the opportunity of observing auroræ in the Shetland Isles in 1817, had already been led to recognise that it is an atmospheric phenomenon, by the consideration that the arcs and the coronæ of the aurora in no way participate in the apparent motion of the stars from east to west, a proof that they are drawn along by the rotation of the earth. Hence, almost all observers have arrived at the same conclusion; we will in particular cite MM. Lottin and Bravais, who have observed more than a hundred and forty-three auroræ boreales.

It is, therefore, now clearly proved that the aurora borealis is not an extra-atmospheric phenomenon. To the proofs, drawn from the appearance itself of the phenomenon, we may add others deduced from certain effects, which accompany it, such as the noise of crepitation, which the inhabitants, nearest to the pole, affirm that they have heard when there is the appearance of an aurora, and the sulphurous odour, that accompany it. Finally, if the phenomenon took place beyond our planet and its atmosphere, why should it take place at the polar regions only?

M. de Tessan, who, in the voyage of the *Venus* round the world, had the opportunity of seeing a very beautiful aurora australis, which he describes with much care, also considers that this phenomenon takes place in the atmosphere. The summit of the aurora borealis being in the magnetic meridian, it was elevated only 14° above the horizon, and the centre of the arc was on the prolongation of the dipping needle, the dip being about 68° at the place of the observation. M. de Tessan did not hear the noise arising from the aurora, which he attributes to the circumstance that he was too far distant from the place of the phenomenon; but he reports the observation of a distinguished officer of the French

sought for, and r, the radius of the earth. We are able, by employing the mean relation of the angular movement of the feet and of the arcs of the aurora, determined by means of a certain number of observations, to get rid of the hypothesis of equality of velocities.

navy, M. Verdier, who, the night of Oct. 13th, 1819, being in the latitude of Newfoundland, had heard very distinctly a sort of crackling or crepitation, when the building that he ascended, was in the midst of an aurora borealis.

Moreover, it finds its confirmation in the fact, generally admitted by the inhabitants of the northern regions, that, when the auroræ appear low, a crackling is heard, similar to that of the electric spark. The Greenlanders think that the souls of the dead are then striking against each other in the air. M. Ramm, inspector of forests in Norway, wrote to M. Hansteen in 1825, that he had heard the noise, which always coincided with the appearance of the luminous jets, when, being only ten years old, he had traversed a prairie covered with snow and hoarfrost, near to which no forests were in existence. Dr. Gisler, who for a long time dwelt in the north of Sweden, remarks that the matter of auroræ boreales sometimes descends so low, that it touches the ground; at the summit of high mountains, it produces upon the face of travellers an effect analogous to that of wind. Dr. Gisler adds, that he has frequently heard the noise of auroræ, and that it resembles that of a strong wind, or the whizzing that certain chemical matters produce in the act of their decomposition. M. Necker, who has described a great number of auroræ, which he observed at the end of 1839, and at the commencement of 1840, in the Isle of Skye in Scotland, never himself heard the noise in question; but he remarks that this noise has been very frequently heard by a person charged with meteorological observations at the lighthouse of Swenburg Head (at the southern extremity of Shetland). Moreover, M. Necker, like all the other observers, notices the white frosts, the falls of rain and snow, as accompanying the appearance of auroræ. M. Necker is not the only one, who has not heard the noise; neither have MM. Lottin and Bravais, who have observed so great a number of auroræ, ever heard it; and a great number of observers are in this case. This divergence may be due to the fact, that it is necessary to be very near to the aurora, in order to hear the crepitation in question; and to the fact

that it is possible also that it does not always take place, at least in a manner sufficiently powerful to be heard.

We have just been pointing out as concomitant effects of the aurora borealis, a noise of crepitation, analogous to that of distant discharges, and a sulphurous odour, similar to that which accompanies the fall of lightning. M. Matteucci has also observed at Pisa, during the appearance of a powerful aurora borealis, decided signs of positive electricity in the air. But of all phenomena, those which most invariably take place at the same time as the appearance of an aurora borealis are the magnetic effects. Magnetised needles suffer disturbances in their normal direction, which causes it to deviate generally to the west first, then afterwards to the east. These disturbances vary in intensity; but they never fail to take place, and are manifested even in places in which the aurora borealis is not visible. This coincidence, proved by M. Arago, without any exception, during several years of observation, is such that the learned Frenchman has been able, without ever having been mistaken, to detect from the bottom of the cellars of the Observatory of Paris the appearance of an aurora borealis in our hemisphere. M. Matteucci has had the opportunity of remarking, under a new and remarkable form, this magnetic influence; he saw, during the appearance of the aurora borealis of November 17th, 1848, the soft iron armatures employed in the electric telegraphs, placed between Florence and Pisa, remain attached to their electro-magnets, as if the latter were powerfully magnetised, without however the apparatus being in action, and without the currents of the piles being set in action. This singular effect ceases with the aurora; and the telegraph, as well as the batteries, could operate anew without having suffered any alteration. Mr. Highton has also observed in England a very decided action of the aurora borealis upon a telegraph wire; the telegraph was put out of use for three hours by the effect of the aurora borealis on November 17th, 1848; the magnetised needle was always driven on the same side, even with much force.

M. de Tessan cites also an observation made in 1818, in

the same latitudes of Newfoundland in which those were made of which we have already spoken, by a naval officer, M. Baral, who perceived at the end of some days, that a false route had been made by following the indications of the compasses; and a verification having been made, all the compasses on board were found erroneous. There had not been, however, since the last observations of magnetic declination, any storm, any thunder, any apparent electric phenomena; the compasses had not been touched. Only, on the very evening of the day in which the last observation of declination had been made, there was one of the most brilliant auroræ boreales; and M. Baral had not hesitated to attribute to the influence of this aurora the errors of the compasses, a conclusion the less suspected of being dictated by theory, since at this period (1818) the relations between electricity and magnetism were not yet known.

The intimate and constant connection that reigns between the phenomenon of the aurora borealis and terrestrial magnetism has led M. de Humboldt, we have already said, to designate under the name of *magnetic storm*, the whole of the disturbances that are manifested in the equilibrium of the magnetic forces of the earth. The presence of this storm is indicated by the oscillations of the magnetised needle, and then by the appearance of the aurora, of which these oscillations are as it were the forerunners, and which itself puts an end to the storm, as in electric storms a phenomenon of light, — lightning, announces that the equilibrium momentarily disturbed has just been reinstated finally into the normal distribution of electricity.

If we compare the details, that we have just been giving, with the laws of electricity and magnetism, which we have already stated, it seems to me that we need not go elsewhere than in electricity itself, and in the mutual influence which this agent in a state of motion and magnetism exert upon each other, to seek for the origin of the aurora borealis, and for the explanation of the phenomena that accompany it. From what we are about to demonstrate before entering upon the numerous observations, that we have yet to relate upon the phenomenon itself, — observations, the results of which,

as we shall see, will furnish to us a remarkable confirmation of the truth of our theory.

We have seen that the atmosphere is constantly charged with positive electricity, — electricity furnished by the vapours that rise from the sea, essentially in tropical regions, and that on the other hand, the earth is negatively electrised; the recomposition or neutralisation of the two contrary electricities of the atmosphere and of the terrestrial globe, is brought about by means of the greater or less moisture with which the lower strata of the air are impregnated. But, it is especially in the polar regions, where the eternal ices, that reign there, constantly condense the aqueous vapours under the form of haze, that this recomposition must be brought about; the more so, as the positive vapours are carried thither and accumulated by the tropical current which, setting out from the equatorial regions, where it occupies the most elevated regions of the atmosphere, descends in proportion as it advances towards the higher latitudes, until in the neighbourhood of the poles, where it comes into contact with the earth. It is there then that the discharge between the positive electricity of the vapours and the negative of the earth must essentially take place, with accompaniment of light, when it is sufficiently intense; if, as is almost always the case near the poles, and sometimes in the higher parts of the atmosphere, it meets on its route with extremely small icy particles, which constitute the hazes, and the very elevated clouds.

We have already said, and we shall see fresh proofs of it further on, that the appearance of the aurora borealis is effectively connected with the presence in the atmosphere of these particles of ice, forming as it were a kind of thin haze which, becoming luminous by the transmission of electricity, must appear simply as an illuminated surface of greater or less extent, and more or less cut up. The phenomenon actually takes place in this manner in the parts of the atmosphere that are the most distant from the earth. We perceive what are termed *auroral plates* of a purple or reddish violet colour, more or less extended, according as

this species of veil, formed by icy particles, extends to a greater or less distance from the poles. The tenuity of this veil is such that it permits of our seeing the stars through the auroral plates; and, with regard to its existence, independently of the indirect proofs that we have given of it by the appearance of the phenomena that are its consequence, we have a direct demonstration of it in the observation of MM. Bixio and Baral, who, being raised in a balloon to a great height, found themselves on a sudden, although the sky was perfectly serene and the atmosphere cloudless, in the midst of a perfectly transparent veil, formed by a multitude of little icy needles, so fine that they were scarcely visible.

Now, if we examine what ought to take place in the portion of the luminous haze, which is nearest to the terrestrial globe, and consequently to the polar regions, we shall find that the magnetic pole * should exercise over this electrised matter, which is a veritable movable conductor, traversed by a succession of discharges, an action analogous to that which is exercised in the experiment that we have described when engaged with the luminous effects of electricity, by the pole of an electro magnet over the jets of electric light that are made to converge in extremely rarefied air. † We have seen that, as soon as the soft iron cylinder, which serves as an electro-magnet, is magnetised, the electric light, instead of coming out indifferently from the divers points of the upper surface, that serve as a pole, as had taken place before the magnetisation, comes out only from all the points of the circumference of this surface, so as to form around it as it were a continuous luminous ring. This ring possesses a movement of rotation around the magnetised cylinder, sometimes in one direction, sometimes in another, according to the direction of the discharge and the direction of the magnetisation. Finally some more

* We designate under this name the point of application of the resultant of the magnetic forces emanating from the globe, without pre-occupying ourselves with the nature and the origin of these forces.

† Vol. ii. p. 308. *fig.* 218.

brilliant jets seem to come out from this luminous circumference, without being confounded with the rest of the group. As soon as the magnetisation ceases, the luminous phenomenon again becomes what it had been previously, and what it generally is, in the experiment known under the name of the *electric egg*.

Now, what takes place on the small scale, in the experiment of which we have just been speaking, is exactly what takes place on the large scale in the phenomenon of the aurora borealis. M. Hansteen *, and after him MM. Lottin and Bravais, have been led to admit as a consequence of their numerous observations that the arc of the aurora borealis is a luminous ring, the different points of which are sensibly at equal distances from the earth, and which is centred around the boreal magnetic pole, so as to cut at right angles all the magnetic meridians, that converge towards this pole.† Such a ring, seen by an observer, placed at the surface of

* The following is exactly how M. Hansteen expresses himself upon this point, without having any preconceived idea, and simply according to observations :—

"The auroræ frequently come out of a zone determined by the earth, forming a ring placed around the magnetic pole, and without doubt situated in North America. A zone or circle of light is then traced in the heavens ; which may be considered as traced upon a sphere concentric to the earth. If a horizontal plane is made to pass through the point, in which the place of observation is situated, we see from this point only an arc of the circle ; we see more than the half of it from Christiania, on account of the elevation ; and it there appears elliptical, on account of the obliquity of its situation. I have twice seen the ellipse almost entire. Most commonly we see here (Christiania) the summit of the arc, or its point, that is nearest to us, in the north of our zenith; but in Iceland and Greenland it is almost always within the circle. In Iceland, the summit of the arc is perceived at the south in the magnetic meridian. In Greenland, where the declination approaches 90°, and where consequently the arc is directed from the south to the north, its summit appears at the east. That the boreal light usually comes out in emanations from a large or small circle, traced around the magnetic pole, appears evident to me by the following observation : *During the aurora borealis, and several days afterwards, the horizontal intensity is notably diminished;* and it only recovers its customary value gradually. On the contrary, *the mean diurnal declination remains almost invariable.* The effusion taking place in a zone cut symmetrically by the magnetic meridian, the intensity is alone affected, without the mean direction being changed. When certain filaments come out of the earth, luminous rays seem to dart from the arc. In order that the hissing may be heard, at the place of observation, it is necessary that the filaments dart from the earth with vehemence all round the observer, and in a very calm air."

† M. Quetelet, on exploring the accounts of ancient observations, has found in the position of auroræ boreales a displacement, which would indicate that from the time of Aristotle, 2,200 years ago, the most powerful magnetic region was 24° to the east of Brussels instead of 20° to the west as it is now.

the ground, evidently presents to him the known appearance of the arc of the aurora; and its *apparent* summit is always necessarily situated in the magnetic meridian of the place. M. Bravais observes besides that the arc seems to undergo a sort of movement of rotation from the west to the east, passing through the south. All this description of the phenomenon is perfectly in accordance with the result of the experiment that I have just been referring to; and the direction of the movement of rotation of the luminous ring is precisely that which ought to take place according to the laws that regulate the mutual action of currents; if it is indeed positive electricity that comes out from the atmosphere in order to direct itself toward the surface of the ground, to penetrate into it around the north magnetic pole, to reunite with the negative, and thus to constitute the current.

The diameter of the luminous ring is greater, in proportion as the magnetic pole is more distant from the surface of the ground, since this pole must be situated upon the intersection of the plane of the ring with the axis of the terrestrial globe; if we could determine rigorously the position of the aurora borealis, we should then have the means of knowing exactly that of the pole itself.

It follows from that which precedes that each observer thus sees the summit of the auroral arc at his magnetic meridian; it is therefore only those who are on the same magnetic meridian who see the same summit, and who are able, by simultaneous observations, to take its height.

If the summit of the arc passes beyond the zenith of the observer, the latter is surrounded in all directions by the matter of the aurora borealis, which comes out of the earth.* Then it is that, by being nearer to the spot, in which the phenomenon is taking place, he hears the whizzing that we have been pointing out, especially if he is in an open country and in a quiet place; whilst, if the arc

* This matter is nothing else than the aqueous vapours, traversed by the discharges, and which are in general luminous only at a certain height from the ground, either because the air there is more rarefied, or because they are themselves congealed, and more susceptible consequently of liberating their electric light.

does not attain to his zenith, the observer is situated beyond the region in which the emanation of the electric current is brought about; he sees only an arc a little more elevated to the north or the south, according as he is situated in one hemisphere or the other; and he hears no noise, on account of his too great distance. The whizzing, of which we have been speaking, is the result of the action of a powerful magnetic pole upon luminous electric jets, very near to this pole, as has been proved to me by the direct experiment, by which I have succeeded in producing a perfectly similar noise by bringing the luminous arc that is liberated between the poles of a voltaic battery, near to a piece of iron powerfully magnetised.* With regard to the sulphurous odour, which some observers have perceived, being also in the midst, so to speak, of the aurora borealis, it arises, as does that which accompanies the fall of lightning, from the conversion into ozone of the oxygen of the air, by the passage of electric discharges.

The light of the aurora borealis is not polarised; this had been already remarked by M. Biot in 1817, in his observations in the Shetland Isles. This negative result has been confirmed by Mr. Macquorne Rankin, who has shown that this absence of polarisation is not due to the feebleness of the light of the aurora borealis, since this same light, seen by reflection upon water, is found to be polarised by the effect of this reflection. Now, the most attentive study of artificial electric light, as well that of discharges through the air as that of the voltaic arc in vacuo, has not enabled us to discover the smallest trace of polarisation; a fresh proof of the identity of the two classes of phenomena. But it is especially in the concordance of the appearance of auroræ with that of certain clouds, as well as with the disturbances of the magnetised needle, that we find a further important confirmation of our theory.

The observations of Dr. Richardson, of which we have spoken above, in showing that the aurora is found at heights

* Vol. ii. 229. et seq.

which are not considerable, indicates at the same time, that it is connected with the formation and the varied modifications of the *cirro-stratus*. Lieut. Hood, in speaking of the movement of the luminous bands of the auroræ, says that he is convinced that they are carried about by the wind, because the columns preserve exactly their relative situation, which never takes place when luminous matter moves in the air by its direct and proper action. Finally, what proves the co-existence with the aurora borealis of small needles of ice in the atmosphere, such as are found in the elevated clouds, is the observation of Dr. Richardson, who, in a temperature of nearly 57° below freezing point, having seen an aurora, the upper arc of which was near to the zenith, remarked that, although the sky appeared perfectly serene during the phenomenon, a fine snow was falling, scarcely perceptible with the naked eye, but which was easily recognised when it was received upon the hand and melted there. The same fact had been previously observed with a brilliant sun, the rays of which permitted of our very distinctly seeing the needles of ice that were floating in the air.

All observers agree as to the existence of a stratus, an obscure segment which, resting upon the northern horizon, appears to be the basis of all auroræ boreales. This at least is what results from the numerous observations of M. Strüve at Dorpat, and from those of M. Argelander at Abo; it is as it were a veil, which, although allowing the light of the stars to pass, gives to the sky a more sombre aspect; then, this obscure segment ends by being bounded by a luminous arc. The existence of this obscure segment is confirmed by the observation of Gisler, who says that in Sweden, upon the high mountains, the traveller is sometimes suddenly enveloped in a very transparent fog, of a whitish gray, passing a little to green, which rises from the ground and is transformed into an aurora borealis.

The cirro-cumulus and the hazes become luminous, when they are traversed by sufficiently energetic electric discharges, and when the light of day is no longer there to efface their more feeble light. However it may sometimes happen

that they are perceived even by day; thus M. Arago established in a decided manner that Dr. Henry Usher was not deceived in a notice published in Vol. II. of the *Memoirs of the Irish Academy*, when he describes an aurora borealis seen in the open day, at noon, on May 24, 1778. This observer, in the day that followed a night in which he had observed a brilliant aurora borealis, having found that the stars oscillated much in his telescope, perceived in the sky rays of a white and vacillating light, which rose from all points of the horizon towards the pole of the inclination needle, where they formed a slight and whitish cupola, similar to that which the most brilliant auroræ boreales present at night. M. Arago has proved, by consulting the ancient registers of the Observatory, the considerable disturbances which the diurnal variation needle suffered at the same moment; a proof that the phenomenon observed by Dr. Usher was indeed an aurora borealis by day.

We likewise find, in the relation of M. de Tessan, of the voyage of the *Venus*, that M. Cornulier, a very well educated officer of the Royal Navy, has frequently observed in the latitudes of Newfoundland, a particular direction that the cirrus assume by day, which always announces for the night a beautiful aurora borealis.* M. Cornulier, in accordance with M. Verdier, is convinced, by studying the arrangement of these cirrus, that there are auroræ boreales almost always in these latitudes, and that their brilliancy alone is variable; he thinks that if they are not all observed, this is due to the circumstance, that the haze and clouds of the lower strata screen them from view. This remark is entirely in accordance with the observations of auroræ boreales, which have now been made for four years in a very careful manner in the northern hemisphere, at Canada in particular. Captain Lefroy has registered, at the magnetic observatory of Toronto, the observations of auroræ boreales

* There is no doubt but that the direction which is assumed by the cirrus, especially toward the polar regions, is due to the electricity which they transmit; a transmission which might likewise explain the phosphorescence that they sometimes manifest.

that are made under his direction, in different stations to the number of thirteen, not including other very numerous observations, made in the United States, and which are collected by Professor Henry, Secretary of the *Smithsonian Institution.* It follows from all this collection of observations that the aurora borealis appears in almost all clear nights, and in which the full moon does not shine with too great brilliancy; but it does not show itself at the same time at all the stations. This is true especially for the months whose days are the longest. From October to March; — it may be said that in these months, there is scarcely a night in which an aurora borealis is not perceived: but it is in February that they are the most brilliant. It follows, from the Tables, which give the number of auroræ perceived in each month of the year, that they were perceived in all during 261 nights in 1850, and during 207 in 1851. A very remarkable thing, but very natural however, is that the proportion of nights in which the auroræ is seen is much greater as we are nearer to the magnetic pole.

Returning to the co-existence of the icy particles in the air with the auroræ, we find a striking proof of it in the observations made at Canada and in the United States. Registers of meteorological observations, kept with much care, indicate the state of the atmosphere on the days that preceded and that follow the appearance of auroræ boreales. Now almost always, the aurora is preceded by the fall of rain, and especially of snow; it also happens very frequently, but not always, that the fall takes place after the aurora. Finally, the appearance of lunar halos which most frequently precedes that of auroræ boreales, is a proof of the presence in the atmosphere of those icy particles, which form the illuminated net-work, by the transmission of electricity.

But of all the proofs in favour of the electric origin of the aurora borealis, the most conclusive is that which is deduced from the action which the appearance of this phenomenon exercises upon the magnetised needle. If we examine attentively all the observations that have been made upon

the disturbances which the aurora borealis brings about in the diurnal variation needle, either by M. Arago, at the Observatory of Paris, or by Mr. Forster, by Farquharson, and by all travellers, we can deduce from them the following results: —

1st. In the day that precedes the night in which an aurora borealis should appear, the declination of the needle to the west is always sensibly increased 10′, 20′, 30′, and even more.

2nd. At the middle and at the end of the appearance, the needle deviates on the contrary more to the east than it should do in its normal state.

3rd. Finally the needle frequently undergoes, during the period of the phenomenon of the aurora borealis, irregular oscillations, the amplitude of which may be some minutes of a degree.

It commonly happens that, for auroræ boreales which show themselves in the evening, it is at noon or at an hour after noon that the declination needle presents its maximum of deviation to the west,; the disturbance may cause the needle to deviate from 5′ to 30′ and more, beyond what it deviated at the same hour the following and the preceding days. Sometimes it is at other hours, in the morning for example, that the maximum of western deviation takes place; it is probable that this is due to the appearance of an aurora borealis in the day. M. Arago cites several cases of this; thus, on August 17, 1825, the declination was from 8 and 8·30 A.M. until noon constantly 5′ higher than the mean of the month for the same hours; and on the same day at 10 in the evening, MM. Coldstream and Foggo perceived feeble traces of aurora borealis, which were very probably the end of an aurora borealis of the day. In the evening the needle had returned to its ordinary position.

The magnetic observations made in the regions in the vicinity of the pole confirm the considerable influence, exercised over the declination needle by the aurora borealis. Thus at Reykinwik (64° 8′ 15″ N. lat.), MM. Lottin and Bravais, having made numerous observations on the

diurnal variations of declination, comparatively with similar observations made at Paris and at Cherbourg, had been struck by the almost continual disturbances of the needle, which they had attributed to some movements of the ground. Then remarking the concordance of their observations with those made fifty years before (in 1786), by M. Lowenorn, they attain to the conviction that this irregular march of the needle was due to auroræ invisible to them on account of the long presence of the sun upon the horizon. M. Ginge, Danish missionary, had made in 1786 and 1787, some observations upon the magnetised needle, which had led him to recognise that, in the course of twenty-four hours, the declination is commonly found strongest towards the west, from 9 to 10 o'clock in the evening, and most feeble from 9 to 10 in the morning, which he does not hesitate to attribute to auroræ boreales. MM. Lottin and Bravais completely confirm this conclusion, which results from their numerous and excellent observations.

We see therefore that the magnetic observations, made in the regions in the vicinity of the pole, had already, for a long time, seemed to indicate that auroræ boreales should be much more frequent than one thinks; which has just been confirmed in a direct manner by the appearances of auroræ boreales, noticed in the stations of Canada and of the United States.

Thus, the production of auroræ at the boreal and austral poles would be the normal state, under which should be manifested the neutralisation of the positive electricity of the atmosphere with the negative remaining in the terrestrial globe. The neutralisation would not be made in a perfectly regular and uniform manner. It is evident that, according to the greater or less hazy state, and consequently the greater or less conductibility of the atmosphere in the polar regions, the two electricities should neutralise each other with greater or less facility. These differences would be indicated by greater or less deviations of the declination needle, and even by their irregularity, — differences which would not be sensible at great distances from the poles, for example, in the tempe-

rate zone, except so long as they might be very considerable. The greatest deviation to the west, which in latitudes but little elevated generally precedes the appearance of an aurora, would indicate a great accumulation of electricity due to a powerful condensation of vapours in the polar regions, which, by facilitating the reunion of the two electric principles, would increase the intensity of the terrestrial current, directed from the north to the equator in our hemisphere, and would consequently carry the needle more to the west. When once the aurora is visible, this current would become less powerful, because the light itself of the aurora would be a proof of the greater resistance which the reunion of the two electricities encounters, on account probably of the congelation of the particles of water, suspended in the air which constitute the haze *; the needle also should retrograde to the east, which in point of fact takes place. In the higher latitudes, the disturbances of the needle are continual, because the slightest differences in the intensity of the electric discharges which take place in the polar regions, must be sensible there. With regard to the remark of MM. Ginge, Lowenorn, and Lottin, that the maximum of deviation of the needle takes place from 8 to 10 P.M. and the minimum from 9 to 10 A.M., as it is the result of observations made during a few weeks of summer only, it simply proves that, at this period of the year, that is to say, at the period in which the days are longest, the greatest condensation of humidity takes place, as ought to be the case, in the moments that precede and in those that follow the setting of the sun, and the least seven or eight hours after its rising. Besides, according to the observations of Lieut. Hood, included in the voyage of Captain Franklin from February 1st to May 31st, the greatest declination took place between 8 and 9 A.M. and the least at an hour after midnight. Thus, as we see, the epochs of the *maxima* and *minima* of declination are eminently variable with the seasons in high latitudes, in which

* It is clear that the haze, when it commences to form, must be a better conductor than when, subsequently, it finishes by becoming gradually composed of icy particles alone.

the great differences in the length of the days and in temperature must bring about considerable disturbances in the state of the atmosphere, in respect to electric conductibility.

A very curious fact is that it sometimes happens that, when the observer is situated, so to speak, in the middle of the aurora borealis, the action upon the needle may become almost null. This is what Mr. Forster has remarked at Port Bowen, situated more to the north than 65°, which is the latitude of forts Franklin and Enterprise, where Dr. Richardson had, on the contrary, remarked the action of the aurora upon the needle. Indeed, if the needle is situated in the interior of the circle that is formed by the aurora borealis around the magnetic pole, it is no longer under the immediate influence of the electric currents, which are then circulating around it, and not below or above it, and it must suffer from them only a variable and irregular action.

The magnetic action of the aurora borealis is not limited to the declination needle. It follows from the numerous observations of M. Kreil that this action is equally exerted upon the three magnetic elements. It slightly increases the inclination as it does the declination, but less powerfully at the commencement of the appearance of the phenomenon; and it diminishes the intensity,—a proof that the cause, whatever it is, which produces the aurora, is not the same as that which generates terrestrial magnetism, and is independent of it.

We have said that the aurora borealis was probably a daily phenomenon, but only of a variable intensity; these differences in its intensity would account for its not being always perceptible, and for the number of times that it is apparent in the year being less as we are more removed from the polar regions.

There are also very great differences between the months of the year, with regard to the number of auroræ boreales visible in a same place. These differences come out in a striking manner from the two Tables, which comprise the number of auroræ boreales observed each month, during certain numbers of years; the former, given

by M. Hansteen for Christiania, during a period of sixteen years, from 1837 to 1853; the other given by M. Quetelet, according to the observations made at Upsal, from 1739 to 1762, successively by Celsius Hjorter and Professor Bergmann.*

NUMBER OF DAYS DURING WHICH THE AURORA BOREALIS WAS VISIBLE AT CHRISTIANIA, FROM JULY, 1837, TO JUNE, 1853.†

Periods.	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	Sum.
1837–38	0	4	9	4	3	2	0	5	3	4	0	0	31
1838–39	0	1	5	3	5	2	6	4	3	5	1	0	35
1839–40	0	0	1	4	4	2	6	6	11	3	0	0	37
1840–41	0	2	2	2	1	7	6	0	2	3	0	0	25
1841–42	0	2	3	4	11	4	2	5	5	13	0	0	49
1842–43	0	4	4	7	4	5	6	8	11	1	0	0	50
1843–44	0	0	7	4	0	1	3	1	6	1	0	0	23
1844–45	0	2	3	3	3	0	0	2	3	1	0	0	17
1845–46	0	6	1	2	3	0	0	0	3	3	1	0	19
1846–47	0	8	12	4	3	5	2	1	5	6	0	0	46
1847–48	0	1	4	10	4	5	4	4	1	6	0	0	39
1848–49	0	5	4	5	4	5	5	7	6	5	0	0	46
1849–50	1	0	3	6	4	5	3	3	6	1	1	0	33
1850–51	0	0	6	3	0	2	1	4	1	0	0	0	17
1851–52	0	0	3	2	2	4	1	8	7	6	0	0	33
1852–53	0	0	11	2	4	6	1	3	2	2	0	0	31
Sum -	1	35	78	65	55	55	46	61	65	60	3	0	534
Relation, supposing 1000 auroræ boreales per annum -	2	65·5	146	122	103	103	86	114	140·5	112·5	5·5	0	1000

It seems to result from these Tables that the phenomenon of auroræ borealcs assumes an annual periodicity, and presents two very decided *maxima* at the epochs of the two equinoxes, and two *minima* at the epochs of the solstices. The minimum of the summer solstice is even so decided that for

* There even exists in Mairan's work *On the Aurora Borealis* a Table of years, anterior to 1739, which, although probably very incomplete, gives results similar to those of the two more complete Tables that we insert.

† Even in August, 1846, the observations were generally terminated at eleven o'clock; nevertheless they were continued throughout the night from November, 1841, to June, 1843. In the period from Aug. 15th, 1846, to the same date of 1847, the observations were made by five observers at each hour of the day and night; the detailed descriptions were made by M. Fearnley, assistant to the Observatory, and by M. Hansteen himself. In the following years, the state of the sky was noted only for the ordinary hours, —2, 4, 10 and 21 hours.

NUMBER OF DAYS DURING WHICH THE AURORA BOREALIS WAS VISIBLE AT UPSAL, IN THE YEARS 1739 TO 1756, AND 1759 TO 1762.

Years.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Sum.
1739	2	3	7	5	0	0	2	7	6	9	2	2	45
1740	3	8	4	0	1	1	0	3	4	8	2	2	36
1741	11	5	9	3	0	0	4	15	9	10	6	4	76
1742	5	4	5	2	0	0	1	8	9	7	2	3	46
1743	1	6	8	4	1	0	0	6	10	11	3	4	47
1744	1	3	1	1	4	0	0	0	1	1	3	3	18
1745*	3	6	—	—	—	—	—	—	—	—	3	7	—
1746	5	10	3	1	0	0	1	0	6	14	3	8	56
1747	3	4	7	0	0	0	0	4	4	4	4	3	33
1748	1	5	7	0	0	0	0	5	7	2	6	6	39
1749	3	4	9	1	0	0	0	4	3	3	2	4	33
1750	3	6	4	0	0	0	1	4	1	4	0	1	24
1751	0	0	3	0	0	0	0	0	3	9	5	4	24
1752	8	9	6	0	0	0	0	1	5	6	4	0	39
1753	0	3	10	8	0	0	0	2	0	0	1	5	29
1754	1	2	5	2	0	0	0	0	1	2	3	1	17
1755	0	2	0	0	0	0	0	0	1	3	2	1	9
1756	1	2	1	2	0	0	0	0	6	3	0	0	15
1759	3	6	4	1	0	0	0	4	11	1	9	12	48
1760	6	9	5	7	0	0	1	3	0	8	9	5	53
1761	9	12	8	8	1	0	0	3	5	2	4	1	50
1762	0	0	3	5	0	0	0	2	8	4	4	8	34
Sum -	66	105	106	50	7	1	10	71	100	111	79	77	783
Relation, supposing 1000 auroræ boreales per annum -	84	134	135	64	9	1	13	91	128	142	101	98	1000

the sixteen years that are embraced by M. Hansteen's observations in the first Table, the presence of one single aurora borealis has not been proved for this month of June; and that during the twenty-three years of the second Table, only one aurora has been observed in this same month.

These differences in the numbers of auroræ boreales visible in each month, are due to two causes; first, to the fact that, in the months in which the nights are shortest, such as May, June, and July, much fewer of them must needs be perceived, although there might even be as many of them as in the others; then, to the fact that there are evidently months in which the auroræ are stronger, since more are seen in March, September, and October, than in the very months in which the days are shortest. The influence of

* The observations of the year 1745, are not comprised in the sums, seeing that they are incomplete.

the two equinoxes is easy of comprehension, according to our theory; indeed, when the sun, in spring, approaches our hemisphere, the quantity of vapours that rise from the sea, to be carried by the tropical current towards the boreal pole, naturally increases much; and as in March and April the atmosphere of the boreal regions is not yet heated by the sun, these vapours are easily condensed there, which does not take place to the same degree in the months of May, June, and July. But, when the sun recedes from these regions, and in particular at the autumnal equinox, all the vapours accumulated during the summer months that have preceded, suffer anew successively a powerful condensation; and the condensation near the poles of the vapours strongly charged with positive electricity, with which the atmosphere is filled, is, as we have seen, the cause of the auroræ boreales. It is probable that an analogous periodicity should exist for auroræ australes; but the observations are not sufficiently numerous to enable us to establish it otherwise than by analogy. This double periodicity would explain the coincidence very generally remarked between the appearance of auroræ boreales and that of auroræ australes. In fact, the passage of the sun, at each of the equinoxes, being for the same hemisphere, the two moments of the year in which, by a different cause, the electric discharges around the pole should be the most abundant, it is evident that the other hemisphere will suffer the same effect from them. Only, whilst, at the autumnal equinox, it will be, for the boreal hemisphere, as at the vernal equinox for the austral hemisphere, the condensation of the vapours accumulated in the preceding months, which will facilitate the escape of the electricity, it will be, at the vernal equinox for the boreal hemisphere, as at the autumnal for the austral, the arrival of fresh vapours in an atmosphere very much cooled down, which will bring a great charge of electricity.

Mairan suggests that there are secular variations in the appearance of auroræ borealcs; namely, that there are epochs comprising a certain number of years, during which more auroræ are seen; and others during which less of them are

seen. He cites in particular a long period in the seventeenth century, from 1621 to 1688, in which no mention is made of any aurora borealis. This philosopher, who regards the aurora borealis as a cosmical phenomenon, and consequently extra-atmospheric, is disposed to attribute these variations to the variable position of the earth, in respect to the solar atmosphere, of which, according to him, auroræ boreales would be an emanation. We may first remark that, in order to compare well, in respect to the frequency of auroræ boreales, ancient epochs with the present, it would be necessary to have, at these epochs, observers as numerous, as exact, and especially as near to the polar regions, as there are now; which is not the case. We cannot therefore place great reliance on Mairan's remark; nevertheless it might happen that the accumulation of ices in the neighbourhood of the polar regions, an accumulation proved by the most positive documents*, must have contributed to increase, in the two last centuries, the number of auroræ boreales. Indeed, the aurora borealis being, according to us, only the luminous effect of the electric discharges, which take place around the poles, between the ground and the vapours that are carried thither, it is necessary, in order to the production of this effect, that the discharges should meet, on their route, with icy particles, and that consequently the ground itself must be covered with ice. At the period therefore, in which the regions situated round the magnetic pole, were not constantly covered with ice; when, in particular, they were the sea itself, electric discharges might indeed have taken place, but discharges that were little, or not at all, luminous. We therefore easily conceive that the displacement of the polar ices, joined to that of the magnetic pole of the earth, must, for the moment, have brought about conditions that are little favourable to the appearance of the aurora borealis. A very

* It is well known that the coasts of Greenland, at present bounded by the great bank of ice called *icebergs*, were formerly free and easily accessible; we have, as we have already seen, been generally disposed to attribute the permanent establishment of this ice to an upheaving of the bottom of the sea, that now arrests them, instead of allowing them to float, as they did when the sea was deeper.

remarkable thing is that this long period, without an aurora borealis, coincides with the epoch during which the magnetised needle was exactly directed in the terrestrial meridian (anno 1662).

We will not dwell upon certain other facts of periodicity, that have also been remarked, such as a return of the aurora borealis on the same day of the year; thus, there was observed, on Oct. 18. 1836, and Oct. 18. 1837, an aurora borealis; and, in general, it has been remarked, that from 1837 to 1850, namely during thirteen years, the phenomenon has been 14 times reproduced, from the 12th to the 22nd of October. But this frequency of the appearance of the aurora borealis, in the days in question, is very probably due to the fact that the month of October is one of the months of the year in which there are more auroræ borcales; consequently the periodicity belongs to the month and not to the day; it is explained, as we have said, by the influence of the position of the sun upon the production and the condensation of the vapours.

We may terminate this long Section upon auroræ borcales by the following summary: —

1st. All observations concur in demonstrating that the aurora borealis is a phenomenon having its seat in the atmosphere, and which consists in the production of a luminous ring, having for its centre the magnetic pole, and of a greater or less diameter.

2nd. Experiment demonstrates that, on bringing about in rarefied air the reunion of the two electricities, near to the pole of a powerful artificial magnet, a small luminous ring is produced, similar to that which constitutes the aurora borealis, and animated by a similar movement of rotation.

3rd. The aurora borealis would be due consequently to electric discharges taking place in the polar regions between the positive electricity of the atmosphere and the negative of the terrestrial globe.

4th. These electric discharges, taking place constantly, but with intensities variable, according to the state of the atmosphere, the aurora borealis should be a daily phenomenon,

more or less intense, consequently visible at greater or less distances, and only when the nights are clear; which is perfectly in accordance with observation.

5th. The phenomena that accompany the aurora borealis, such as the presence and the form of cirro-stratus, and especially those which are relative to the disturbances that the magnetised needle undergoes, are of a nature to demonstrate the truth of the electric origin, that we have been attributing to the aurora; an hypothesis with which these phenomena are reconciled, even in their smallest details.

6th. The aurora australis, as results from the small number of observations, of which it has been the subject, present exactly the same phenomena as the borealis, and is explained consequently in the same manner.

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PART VII.

APPLICATIONS OF ELECTRICITY.

CHAPTER I.

PHYSICAL APPLICATIONS.

Application of Electricity to the Production of Light and Heat.

THE applications of electricity, for a long time restricted to certain therapeutical attempts and to purely scientific researches in chemistry, have acquired within fifteen or twenty years an immense development, and are probably still destined to extend greatly. We have classified them into three great divisions, founded, not upon their own nature, but upon the nature of the properties of electricity. We shall in studying them follow the same order that we have followed in the examination of the properties themselves, which have formed the subject of the Fourth Part (Vol. II.). Thus, we shall first occupy ourselves with the applications founded upon the physical properties of electricity; namely, upon the faculty, possessed by electricity in motion, of producing light and heat, and of exerting an electro-magnetic action. Then will come the chemical applications, in which it is the property of the current to act chemically upon the body that it traverses, which is put under contribution. Finally, we shall terminate by the physiological applications, which consist in utilising, for the art of healing, the very remarkable physiological effects that electricity is able to produce.

We shall commence in this First Chapter, devoted to

physical applications, by that whose object is the production of light and heat.

We have seen that electricity in motion is able to produce much heat and much light; we have analysed the laws of this production, at the same time that we have studied the particular properties of this light and heat. We have described an apparatus, intended to give more fixity, than it naturally possesses, to the light that bursts out between two charcoal points communicating respectively with the two poles of a pile.* This apparatus is that of M. Jules Duboscq, but it is right to acknowledge, that the first idea of these apparatus belongs to Messrs. Staite and Petrie, who constructed one in 1848, almost at the same time that M. Foucault, on his part, constructed one in France. It was not until after these trials that MM. Breton, Brothers, M. Duboscq, M. Martin de Brette, and M. Liais, have also successively devised apparatus, founded upon the same principle, but with some modification in the details.

The most simple of these apparatus is that of Mr. Staite, especially since the modifications that have been introduced into it by M. Archereau. Two metal columns or stems, to which any desired form may be given, are connected together by three cross-pieces, so as to form one solid frame; one of these cross-pieces is metallic; it is the one that occupies the upper part of the apparatus; the others must be of wood. These latter serve as supports and points of attachment to a long bobbin placed parallel to the two columns and between them, and which must be made of a tolerably thick wire in order that the current, in traversing it without melting it may act upon a soft iron rod placed in the interior of the bobbin. This iron rod is soldered to a brass stem of the same calibre, and of the same length, carrying at its free extremity a small pulley. On the opposite side the iron carries a small brass tube, with binding screws, into which is introduced one of the carbons, when the entire rod has been placed in the interior of the bobbin. Then, a cord,

* *Vide* Vol. II. p. 327. *fig.* 226.

fixed to the lower cross-piece, and rolling over a pulley of a large diameter, is able to serve as a support to the movable iron rod running in the groove of the little pulley. For this purpose, it only requires that a counterpoise placed at the end of the cord shall be enabled to be in equilibrio with it.

The metal cross-piece, which occupies the upper part of the apparatus, carries a small brass tube, which descends perpendicularly in front of the carbon, that is carried by the electro-magnet stem, and into which is also introduced a carbon crayon. By means of a very simple adjustment, this tube may besides be easily regulated, both for its height and for its direction; and consequently, the two carbons may be placed very exactly one above the other.

Thus arranged, the apparatus is able to act; but it is of importance to adjust it, and especially to balance well the movable stem. This being done, we have merely to place one of the two metal columns of the apparatus in connection with one of the poles of the pile, and to cause the other pole to abut upon the copper wire of the bobbin (one end of which is soldered upon its socket). The current then passes from the bobbin to the lower carbon by the rod itself that supports it; and, passing over the interval separating the two carbons, it arrives at the other pole of the pile by the upper cross-piece of the apparatus and the metal column, to which one of the conducting wires is attached.

So long as the current is passing and producing light, the bobbin reacts upon the iron of the electro-magnet rod, which carries the lower carbon, and attracts it on account of the magnetic reaction that solenoids exercise over a movable iron in their interior. It is this which gives to the carbons a *separation sufficient* for the luminous effect. But, immediately the current ceases to pass, or is weakened, in consequence of the consumption of the carbons, this attraction ceases, and the movable carbon, acted on by the counterpoise, is found to be drawn on, and raised until the current passes again; equilibrium is again established between the two forces, and the carbons may be employed again. Thus, in

proportion as the light tends to decrease, the counterpoise reacts; and this it is that always maintains the intensity of the light equal.

Many precautions must nevertheless be taken when we desire that the apparatus shall act very regularly. We must first place the carbons at a height, which depends upon the intensity of the pile, that is about to be employed. If the pile is very powerful, the carbons must be placed a little high; for the attraction of the solenoids increases, at least as far as the half of their length, in proportion as the iron is buried in them. On the contrary, and for the same reason, the carbons must be placed lower, if the pile is feeble. On the other hand, as the pile itself becomes weaker, care must be taken to lighten the counterpoise, from time to time, in order to maintain the equilibrium; on this account it is that leaden shot are in this case employed as a counterpoise.

The inconvenience of the preceding apparatus, which, however, possesses the advantage of being very simple, and consequently less susceptible of getting out of order, is that the luminous point is displaced in proportion as the carbons are consumed. Now, it is important, under many circumstances, and particularly in the application of the electric light to optical experiments, that this luminous point should remain fixed; a condition, the more difficult of fulfilment, as the carbons are unequally consumed. It is to mechanical means that we must have recourse, in order to obtain the desired result. These means are all founded upon the employment of clock-work, moved by springs or by weights, which imparts to the carbons the movement necessary for bringing them near to each other, as soon as the current, on account of their too great separation, no longer passing, the light ceases to be produced. Now, the apparatus is combined so that this same current traverses the wire, that surrounds an electro-magnet, the energy of which varies with the intensity of the current; this electro-magnet acts upon a piece of soft iron, induced on the other hand to recede from it by an antagonistic spring. Upon this movable soft iron is mounted the detent, that locks the train of wheels, or

allows them to run on, as required; and the direction of the movement of the detent is such that it presses on the train of wheels, when the current is strengthened, and that it liberates them, when the current is weakened. Now, as the current is strengthened or weakened, precisely when the distance between the carbons diminishes or increases, we perceive that the carbons acquire the property of approaching each other, at the very moment when their distance begins to increase; and that this approximation cannot go on as far as to contact, because the increasing magnetisation, that results from it, soon opposes to them an insurmountable obstacle, which disappears of itself, immediately that the interpolar distance has increased anew. The approximation of the carbons is therefore intermittent; but, when the apparatus is well adjusted, the periods of rest and advance succeed each other with sufficient rapidity for being an equivalent to continuous movement of progression.

The apparatus that we have just been describing is that of M. Foucault; that of M. Breton differs from it only in that, instead of springs for approximating the carbons, weights and counterpoises of the metallic arms that carry them are employed; and that, instead of a pressing detent, for maintaining the separation, a click and finely-toothed ratchet wheel is called into play. There are levers that act upon the porte-carbons; and, consequently, it is by the difference in their length, that the inequality in the march of the two carbons is brought about.

In M. Duboscq's apparatus, which we have already described in the Fourth Part of this Treatise, the mechanism, as we have seen, is so combined, that the positive carbon is animated by a more rapid movement than the negative, in order to compensate for the greater consumption that it undergoes, on the part of the current. This mechanism is very complicated; but, notwithstanding, by taking care to adjust it suitably in each experiment, that is to say, to give to the antagonistic springs of the detent the suitable degree of tension, and to the pulley of variable diameter, the diameter required in order that the approximation of the carbons may be

as regular as possible, we succeed in obtaining a light of a remarkable regularity and fixity.

M. Martin de Brette has contrived to add to the regulator of the electric light a rotatory amplifying apparatus, which enables us to project in a continuous manner, and in all directions, to the distance of a mile or two, an excessively brilliant light. This apparatus contains six light-house lenses, mounted upon a cast-iron wheel, which is adjusted upon a frame also of cast-iron, movable, like the wheel itself. By means of a peculiar mechanism, motion is imparted, first to the frame, then to the system of lenses; and this double movement, properly calculated, is sufficient to direct a pencil of light successively into different points of space, and to illuminate them in a continuous manner. It is sufficient for this, that the lenses pass ten times per second in the same direction; in order to obtain this result, it is necessary that the wheel, which carries the lenses, should make about two turns per second, whilst the frame that carries it accomplishes five. With regard to the regulator itself, that M. Martin de Brette employs, it differs from the others in some points of but little importance, upon which it is useless to dwell.

We shall confine ourselves again to pointing out the system of electric illumination, proposed by M. Liais, in which, in order to obtain a more regular and especially a less jerking light, the regulator should act in a constant manner, and independently of the carbons. A commutator moved, either by an electric motor or by a clock-movement, should be applied to the apparatus, in order, by reversing at very restricted intervals, the direction of the current, to render the consumption of the carbon as equal as possible; then this same commutator would conduct the current alternately into a double system of carbons, which would compose the luminous focus. It would follow from this that, during the time of the change of the current, the carbon would be incessantly approximated to contact, then withdrawn by a constant quantity by the motive mechanism; and this quantity might be regulated according to the intensity of the pile that we might desire to employ. Finally, the

whole of the apparatus would be actuated by a rapid movement of rotation in order to acquire the passage of the current from one to the other system of carbons. M. Liais further proposes to place the carbons themselves in a globe of glass, filled with a gas unfitted for combustion, in order to render their destruction less prompt; a process which I had already pointed out in 1846, on the occasion of the announcement I had made of an apparatus fitted for the illumination of mines.

The electric light, although superior to all other artificial lights by its brilliancy and its radiation, which gives to it the appearance of solar light, has a bluish effect very disagreeable to the eye, which may be rendered rosy, it is true, by employing for the construction of the points, between which the electric arc must burst forth, carbons of alder wood. However this light would be too dazzling, and too little favourable to the objects illuminated, to be employed with advantage for ordinary illumination, even should the cost of obtaining it not cause it to be rejected. It is not useful, therefore, save in some exceptional cases. Thus it may be employed with advantage for the illumination of light-houses; for procuring an artificial light intended, for want of solar light, to reproduce, so that they may be visible to many persons at the same time, the principal experiments of optics, as is done with the greatest success by M. Duboscq. M. Foucault had already, conjointly with M. Donné, employed this light for illuminating several microscopes, intended for demonstrations in a public course of lectures. It is also employed with success for the illumination of works by night, in large undertakings of embankments or masonry, and for scenic effects in theatrical representations. By means of copper wires, covered with gutta percha, the current may be conducted into water, even in great depths, and may produce an illumination applicable to submarine works, especially when explorations at the bottom of the sea, as the saving of sunken objects, is in question. The carbon points may then be enclosed in a glass globe, protected from the contact of the water, or may be plunged in the water itself; for, as we have

seen, the electric light bursts out, even in this case, between the two points; only the arc is not so long. It has lately been proposed to employ this mode of illumination, in order to introduce into water a light intended for fishing.

But of all the applications of the electric light, that which presents the greatest interest is the illumination of mines. Every body knows the danger that miners incur from the effect of *fire-damp;* that is, from the explosion that takes place, when a jet of carburetted hydrogen gas, having escaped through the different beds, encounters the flame of the lamps that illuminate the galleries of the mine. Now, as the electric light has no need of oxygen, nor of any other gas, for its production, since it takes place without combustion, we can enclose the carbon points in a globe hermetically closed; and then we have no longer to fear the slightest danger, the luminous focus being completely isolated from the external air. The first idea of this application is due to M. Louyet and to M. Boussingault; this latter philosopher made it known at the end of certain researches on the Davy lamp, in which he showed that the security that is presented by this lamp, although very great, is not absolute; since a current of hydrogen gas, animated with a certain velocity, and probably other causes still undetermined, may annihilate in a moment the efficacy of the protective envelope, and cause accidents to arise, which we are perhaps too disposed to attribute, in all circumstances, to the imprudence of the workmen, or to the imperfection of the apparatus. M. Boussingault proposes a fixed pile, furnished with long conductors, which permit of conveying the current, and consequently the light, that it produces, wherever there is need of it. I had at the same time with M. Boussingault thought of the same application, and I had proposed to adapt to a globe hermetically closed, in which the two carbon points are arranged and properly prepared, a small and portable, but very powerful pile (amalgam of potassium, and platinum with diluted sulphuric acid, and chloride of platinum), the two poles of which are respectively placed in communication with the interior carbons by means of strong rods of copper, ce-

mented to the globe. Mr. Grove has objected against this arrangement the difficulty of sealing the receiver, in which the electric light is liberated, sufficiently hermetically, so that no communication may be established with the external air, under the influence of the high temperature that is developed in it. He also proposes to substitute, for the light of the carbon points, that which arises from a platinum wire coiled into a helix, and rendered incandescent, by the passage of a voltaic current. The wire is placed over water, in the interior of a glass tube. The helical form presents the advantage that, by diminishing the causes of cooling, it enables the same voltaic battery, to hold in ignition a much longer wire; there results from this not only an increase of light, but a diminution in the expense of the battery, on account of the increase of the resistance. The increase in the intensity of the heat, by increasing the resistance, likewise diminishes the consumption of the materials of the pile, so that, contrary to what generally takes place, the increase of expense diminishes with the increase of effect that is produced, at least within a certain limit.

Mr. Grove has desired to form an exact idea of this expense; with this view he introduced a voltameter into the circuit, knowing that, to one equivalent of hydrogen, collected in the voltameter, corresponds the consumption of one equivalent of zinc, one equivalent of sulphuric acid, and half an equivalent of nitric acid. Taking into account the state of hydration of the acids, it is found that the expense of fifty pairs of nitric acid and platinum, of eight square inches of surface, would amount to four shillings, or five francs per hour, in order to produce a light the intensity of which would be to that of a wax taper as 1444 : 1. The expense of the electric light would therefore be very inconsiderable, in respect to its intensity; however, Mr. Grove considers that it is especially for the illumination of light-houses that it may be employed with advantage.

The heat that is liberated in a conductor which, while still transmitting a current, presents some resistance to its passage, has likewise found important applications. This mode

of production of heat presents, in fact, a peculiar character which permits of its employment in many cases, in which the other modes would not be applicable. This character is, that the heat may be transported to as great a distance as may be desired from the source that produces it; so as to act only upon a determinate point, without manifesting itself the least in the world between this point and the place of its origin. It is particularly to the art of exploding mines that this property, possessed by the electric current, of rendering incandescent a wire that it traverses, has been applied. Mr. Hare is the first who entertained this idea; but it is Mr. Roberts, who devised this most simple process for realising it.

In order not to be called upon to make afresh a new apparatus for each explosion, Mr. Roberts invented cartridges, which may be constructed beforehand. With this view, two copper wires are procured about a tenth of an inch in diameter, and three yards in length, well covered with silk or cotton tarred, so that their insulation may be very good. They are twisted together (*fig.* 361.) for a length of six inches, care being taken to leave their lower extremities free for a length of about half an inch (separating them about half an inch), from which the insulating envelope is removed in order to stretch between them a fine iron wire after having taken the precaution of cleaning them well. The upper extremities of the two copper wires are likewise separated in order to allow of their being placed respectively in communication with the conductors, that abut upon the poles of a pile. The body of the cartridge is a tin tube, three inches long, and three quarters of an inch in diameter, the solderings of which are very well made, in order that it may be perfectly impermeable to water.* The system of copper wires is introduced into the tube, fixing them by means of a stem that traverses it at such a height that the fine iron wire is situated in the middle of the tin tube, so arranged that the ends of the copper wire do not anywhere

* A glass tube might equally well be employed, were it not for its fragility, which has caused a tin tube to be preferred.

touch the sides of the tube (*fig.* 362.). The cork is firmly fixed at the upper extremity of the tube with a good cement*;

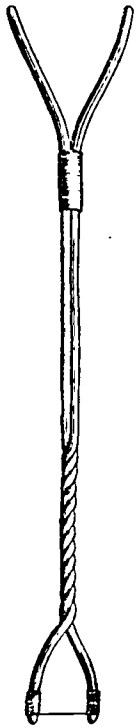

Fig. 361.

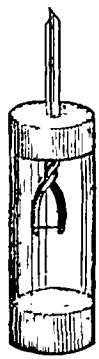

Fig. 362.

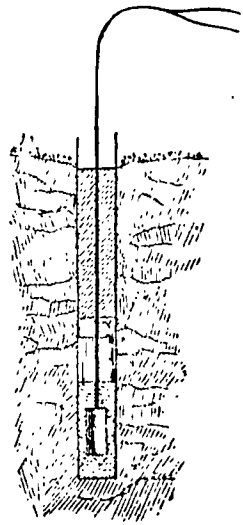

Fig. 363.

the tube is then filled with powder by its other extremity, which is likewise stopped with a cork that is cemented in the same manner. *Figure* 363, indicates the manner in which the cartridge is placed in the copper hole, after having carefully expelled all dust and moisture; care must be taken that the cartridge is situated in the middle of the charge of powder that is introduced into the hole. Above the powder is placed a plug of straw or of tow, so as to allow between it and the powder a small space filled with air; and above the plug is poured dry sand, until the hole is filled with it. The two ends of the copper wires that

* Mr. Roberts recommends for this operation a cement composed of one part of beeswax and two parts of resin.

come out of the cartridge are made to communicate with the poles of the pile by means of conductors of sufficient length, that one may be protected from all danger arising from the explosion of the mine.

The method, that we have just been describing, presents the advantage of being able to be employed to blow up rocks or other objects under water, as well as under ground; only, in this case, it is necessary, for the construction of the cartridge, to have cases of sheet iron impermeable to water, and, for conductors, copper wires covered with gutta percha.

M. Ruhmkorff, and after him M. Verdu, have successfully tried to substitute the induction spark for the incandescence of a wire, in order in bring about the ignition of the powder. This process, besides the considerable economy that it presents—since, instead of from 15 to 20 Bunsen's pairs, necessary for causing the ignition of a wire, it requires but a single one, for producing the induction spark,—possesses the advantage of being less susceptible of derangement. Only it was necessary to contrive a plan to bring about the ignition of the powder; in fact, it happens that when, by the effect of the length of the conductors that abut upon the mine, the circuit presents too great a resistance, the induction spark is able to pass through the powder without inflaming it. M. Ruhmkorff has conceived the happy idea of seeking for a medium, which, more easily inflammable by the spark, may bring about the ignition of the powder in all possible conditions. He found it in Statham's fusees, which are prepared by taking two ends of copper wire covered with ordinary gutta percha; their extremities are stripped of the gutta percha; they are twisted (*fig.* 364.), and the ends are bent so as to make them enter into an envelope of vulcanised (sulphured) gutta percha, which has been cut and drawn off from a copper wire that had been for a long time covered with it. Upon this envelope a sloping cut *a*, *b*, is formed;

Fig. 364.

and after having maintained the extremities of the copper wires at about the eighth of an inch from each other, their points are covered with fulminate of mercury, in order to render the ignition of the powder more easy. The cut is filled with powder; and the whole is wrapped round with a piece of caoutchouc tube *c*, *d*, or else it is placed in a cartridge filled with powder.

In the Statham fusees, it is the sulphuret of copper, adhering to the layer of vulcanised gutta percha, which is removed from the copper wire that it covered, which by being inflamed under the action of the induction spark brings about the explosion.* But it is necessary to take care, when the fusee has been prepared, as we have pointed out, to try it in order to regulate hence the extent of the solution of continuity. It might in fact happen that, while still belonging to the same envelope of a copper wire, the sheath of vulcanised gutta percha, with which the fusee is furnished, may be more or less impregnated with sulphuret of copper; now, if the sulphuret of copper is in too great quantity, it becomes too good a conductor and prevents the spark being produced; if, on the contrary, it is not in a sufficiently large quantity, it does not sufficiently facilitate the discharge.

The first trials on a large scale of the application of the process that we just described, were made with Ruhmkorff's induction apparatus, by the Spanish Col. Verdu, in the workshops of M. Herkman, manufacturer of gutta-percha

* The discovery of these fusees is due to an accidental circumstance, which presented itself in the experiments made at London, in connection with the trial of the submarine telegraph from Dover to Calais. For these experiments, the submarine cable had been placed at a considerable depth in the water; when the testing of the wires was in progress the constructor, Mr. Statham, being led to a minute examination of the whole cable by a solution of continuity that he had proved to be in one of the wires, perceived, to his great astonishment, sparks passing through the gutta percha envelope, and succeeding each other with a great rapidity. After having carefully examined the various circumstances under which the phenomenon was produced, he thought he recognised that it was the slight mark of the copper wire upon the vulcanised (sulphured) gutta percha,—a mark due to a layer of sulphuret of copper which brought about the sparks that accompanied the propagation of the electric current; for the sparks always followed this mark. He hence conceived the idea of constructing upon this principle fusees for mines.

covered wire, at La Vilette, near Paris. Experiments were made successively upon a length of wire of 400, 600, 1000, 5000, and up to 26,000 metres (of 3·28 ft.); and the success was always complete, whether with a circuit composed of two wires, or replacing one of the wires by the earth; two ordinary Bunsen's pairs were sufficient for producing the induction spark, with Ruhmkorff's apparatus. Since his first researches with M. Ruhmkorff, M. Verdu has applied himself to fresh researches in Spain: and he has satisfied himself after many trials that, of all explosive substances, not any one was nearly so sensitive as fulminate of mercury; only, in order to avoid the danger that arises from the facility of explosion of this compound, he takes the precaution of introducing the extremity of the fusees into a small gutta percha tube, closed at the end. After having filled with powder this species of little box, and having closed it hermetically, the fusees may be carried about, may be handled, may be allowed to fall, and even squeezed rather strongly without danger. The elastic and leather-like nature of gutta percha, which has been carefully softened a little at the fire, preserves the fulminate from all chance of accident. We may add, that with a simple Bunsen's pair, and by means of Ruhmkorff's induction apparatus, M. Verdu has succeeded in producing the simultaneous explosion of six small mines, interposed in the same circuit at 320 yards from the apparatus; he has not been beyond this limit; but he has sought for the means of acting indirectly upon a great number of mines, by distributing them into groups of five, and by interposing each of these groups in a special circuit. The fusees of each group are made to communicate by a single wire, one of the extremities of which is buried in the ground, and whose other extremity is near to the apparatus. On touching the induction apparatus successively with each of the free ends that are held in the hand, which requires scarcely a second of time, if there are four wires, that is to say, four groups and consequently twenty mines, twenty explosions are obtained simultaneously at considerable distances. There are no limits either to the

distance at which the explosion may take place, or to the number of mines that may thus be made to explode.

M. Dumoncel, in order to obtain more security, and a system unfailing in its effects, prefers to divide the mines into groups of two, to suppress the communication by the ground, and thus employs for each group two conductors instead of one (which does not greatly increase the expense, since one of the wires may be common to all the circuits), and places them in communication with the three or four large mines, which must go off at the same time. In order to obtain with this arrangement the simultaneity of explosion through these different circuits, M. Dumoncel employs a rotative commutator, constructed by means of a thick wheel of gutta percha, the circumference of which carries five metallic plates, separated from each other by an interval of about three-quarters of an inch; but upon this circumference rests a rubber, which, by the intervention of a connecting screw and a wire, communicates with that pole of Ruhmkorff's apparatus which furnishes the spark at a distance. The plates themselves communicate, by the intervention of metal plates placed upon the flat surfaces of the wheel, with five rubbing springs, put into communication by connecting screws with the five wires of the circuits. M. Dumoncel has applied his process with success to the explosion of *monster* mines in the military port of Cherbourg.

Application of the Magnetic Properties of the Current to the Production of a Mechanical Motor.

We have, in our First Volume *, carefully studied the property that is possessed by the electric current of developing in soft iron a magnetisation, the power of which has scarcely any limits. We have likewise seen that the facility with which soft iron acquires and loses its magnetism with the cause that produces it, and the rapidity with which the direction of this magnetism is able to change with that of the current by which it is developed, may give rise, by means of apparatus constructed with this view, to a con-

* Vol. i. p. 289. *et seq.*

tinuous movement either of rotation or of an up and down motion. Several philosophers have endeavoured to turn this motion to a useful account, and have occupied themselves in the construction of machines, the motor principle of which should be the magnetisation produced in bars of soft iron by the passage of electric currents through wires coiled into a helix around these bars. Before describing these apparatus and examining to what point their employment in applied mechanics would be advantageous in the double relation of power and economy, it is well briefly to call to mind, in perfecting them, the notions that we have already given concerning electro-magnets, and the laws by which they are governed. This subject has occupied a very great number of philosophers; and, if their results have not been in accordance, this is due to the circumstance that the phenomena in question depend on too many special circumstances for presenting very general laws. As an example of this, we will give the length of soft iron bars, which, under conditions in other respects perfectly similar, influence according to some the quantity of weight that an electro-magnet is able to carry, whilst it is without influence according to others. Now M. Nicklès has shown * that the former

* M. Nicklès has, by some interesting researches, lately thrown light upon a point contested among the German philosophers, relatively to the influence of the length of the sections of electro-magnets over their magnetic power. MM. Lenz and Jacobi, supported by M. Müller, maintain that under equal conditions, the length of the branches of an electro magnet is without influence over the weight sustained; M. Dub, on the contrary, contends that the attraction of an electro-magnet increases with the length of the bars. M. Nicklès has proved that the proposition of MM. Lenz and Jacobi is true only so long as it concerns ordinary horse-shoes, that is to say, those furnished with two helices in contrary directions. If the two helices are in the same direction, and if the horse-shoe is furnished with only one helix, and finally if the iron bar is rectilinear and not a horse-shoe bar, M. Dub's proposition is verified. This influence of length, according to M. Nicklès, is due to the circumstance that, on elongating a magnetised bar, the poles of contrary names are drawn more apart, and the effects of neutralisation, which these poles may exert upon each other, are proportionably diminished. M. Nicklès has arrived at this conclusion, by taking an iron bar surrounded by a helix of copper wire, which he places in the circuit; he then chooses for an armature a piece of iron, the mass and length of which, variable according to the current, are so taken that this armature may be attracted without remaining suspended. At this moment, he places upon the upper pole of the electro-magnet a cylinder of iron; the armature immediately suspends itself to the magnet, and adheres to it more or less energetically, in order to fall back, as soon as the cylinder that is placed upon the other pole is withdrawn. The following is the Table of some results

proposition is true, if the bar is rectilinear, and the latter if the bar is in the form of a horse-shoe. Nevertheless, let us briefly call to mind the results relative to the powers of electro-magnets, on which by general agreement the greatest confidence has been placed.

In an extensive enquiry on the laws of magnetisation by electric currents, MM. Lenz and Jacobi had established, as the result of a great number of experiments, the law of the proportionality of the force of magnetisation to the intensity of the currents. The magnetisation was measured by the induced current developed in a conducting wire, which surrounded the soft iron bar subjected to magnetisation; account was taken in this measurement of the effect of induction produced directly by the voltaic current. The sum of the results agrees with the law in a very satisfactory manner, notwithstanding the difficulties that were introduced by the employment of a non-constant pile*; and we may regard it as demonstrated that within very wide limits, and *when the diameter of the soft iron bar is not*

obtained with a certain number of cylinders of the same section, and lengths progressively increasing: No. 1. was 1·96 in. in length; No. 2. was 3·93 in.; No. 3. was 4·32 in.; &c. The helix was composed of 308 ft. wire of $\frac{1}{25}$ in. diameter, forming 754 convolutions; the cylinder, placed upon the bobbin, was similar to No. 3. The armature was at the end of the cylinder, and weighed 1142 grains Troy its surface of contact had been rendered convex. Two currents of different force were employed successively.

Current of a force of Tang. 11° 20′.			Current of a force of Tang. 7° 15′.		
Cylinder superposed.	Carries at first	Falls with	Cylinder superposed.	Carries at first	Falls with
	Grammes.[a]	Grammes.		Grammes.	Grammes.
0	1700	1750	0	980	1000
No. 1	1900	2000	No. 1	1100	1150
2	2000	2150	2	1210	1250
3	2150	2240	3	1260	1300

This influence of the lengthening of the magnetised bar upon the magnetic attraction, which is very manifest, has nevertheless a limit, setting out from which the attraction diminishes, in proportion as the length increases. M. Nicklès has also varied his experiments, by employing electro-magnets of a horse-shoe form with a third lateral branch parallel to the other two; the results, which are a little complicated, that he obtains, are yet conformable to the principles that we have been laying down.

* At the period when MM. Lenz and Jacobi conducted their experiments, piles with a constant current, of an invention still recent, were not of general use among philosophers.

[a] Grammes of 15·43 grs. Troy each.

very small in respect to its length, the magnetisation developed by a current, is proportional to the intensity of the current.

Considered as an empirical formula the law of MM. Lenz and Jacobi is of great utility; but its rigorous accuracy has been frequently called into question; and in these latter years, the experiments of M. Müller have shown that no reliance was to be placed upon it. In order to measure the magnetism developed in soft iron, M. Müller employed a method altogether direct and very accurate. He arranged his soft iron bar perpendicularly to the magnetic meridian, and, at some distance, on the prolongation of the axis of the soft iron bar, he placed a declination compass. He observed the deviation that was produced upon this compass by the action of the magnetic helix, when the voltaic current was made to pass into it, without introducing into it any soft iron bar and the deviation that took place when the soft iron bar was introduced into the helix. The difference of the tangents of these two deviations gave the measure of the magnetic moment of the soft iron bar.* The intensity of the current was likewise measured by a tangent compass.

The magnetic helix that was employed by M. Müller was formed of two distinct helices, contained one within the other. The internal helix was 20·9 in. in length, with an interior diameter of 0·58 in. and was formed of 408 spirals of a copper wire 0·12 in. in diameter. The external helix was in length 16·97 in., with an interior diameter of at least 1·76 in., and was formed of 372 spirals of a copper wire of 0·1 in. in diameter. The current might be made at

* M. Gauss has, in fact, demonstrated that if we call R, the distance of the middles of the two bars, situated as in M. Müller's experiment, M the magnetic moment of the fixed bar, T the horizontal component of terrestrial action, R a constant co-efficient, and u the deviation, we obtain with a great approximation:

$$\text{Tang.}\, u = \frac{1}{T}\left(\frac{M}{R^3} + \frac{B}{R^5}\right)$$

It follows from this that, if R is very great, the term $\frac{B}{R^5}$ may be neglected, and the tangent of the deviation is proportional to the magnetic moment of the fixed bar. (*Vide* the memoirs by M. Gauss upon the measurement of the intensity of the terrestrial magnetic force, translated in the *Annales de Chimie et de Physique.* Second series. t. lvii. p. 5.)

pleasure to pass into one or the other of the helices or into both at the same time. The soft iron bars were four in number; they were all 22 in. in length, and respectively 0·35, 0·47, 0·58 and 1·72 inches in diameter.

For the bar of 1·72 inches in diameter, the proportionality of the magnetisation and intensity is verified with tolerable accuracy; but the other bars completely departed from this law. The increase of the magnetic moment always took place in a proportion much less than the increase of the intensity of the current. Of this we may satisfy ourselves graphically, by tracing curves in which we take for abscissæ the intensities of the current, and for ordinates the magnetic moments.

The results of M. Müller's experiments had been contested by MM. Buff and Zamminer, who, by following a method entirely similar to that of this philosopher, had observed a very exact proportionality between the intensity of a voltaic current and the magnetisation that it produces. They had consequently attributed the results obtained by M. Müller to the influence of the coercitive force. In order completely to set aside this objection, M. Müller specially took in hand to demonstrate, in a peremptory manner, a principle to which he had already glanced, as the result of his former researches, namely, the existence, for each soft iron bar, of a maximum of magnetisation, which cannot be passed beyond, — a condition which is evidently incompatible with the law of proportionality.

M. Müller in no way altered the principle of his method. He merely perfected its execution by substituting magnetometers for the compasses of his former experiments. Besides, as MM. Buff and Zamminer had employed much shorter magnetising helices than his (only 3·37 in. in length), he studied the influence that may be exerted by the length of the helices, by taking three different helices of 6 in., 11·79 in. and 20·9 in. in length. He also employed bars of soft iron of various dimensions; and he applied the greatest care to satisfy himself that they were entirely deprived of coercitive force.

The numerical results of the very numerous, and very exact experiments that M. Müller has made, lead us soon to recognise that the proportionality exists within limits of a little extent, only when the diameter of the bars exceeds a certain value, which is greater in proportion as the bar is longer. Thus, a bar of 6·5 in. in length and 0·47 in. in diameter follows with tolerable accuracy the law of proportionality; a bar of 23·1 in. in length and 0·47 in. in diameter departs from it all of a sudden, in a very marked manner. In bars of a small diameter, we see that the proportionality exists only for extremely feeble currents. The existence of a maximum of magnetisation is indicated by the experiments in a most evident manner for the greater part of the bars; for some we might even say that the experiments have attained to this maximum.* The existence of a maximum towards

* The existence of a maximum of magnetisation may be regarded as favourable to Ampère's theory, which we have adopted and developed (Vol. i. p. 232); and in which magnetisation consists in giving to the molecular currents of the iron a direction perpendicular to the axis of the bar. It is evident that when the magnetising force has been sufficiently great to give this direction to *all* the molecular currents, there is no possibility that an augmentation in the intensity of the force increases the magnetism. This point of view has attracted the attention of M. Weber to this question, who, in the third part of his *Electrodynamische Maasbestimmungen* (Leipzig, 1852), has published some experiments confirmative of those of M. Müller. The method of observation was exactly the same; the iron bar studied was 3·93 in. in length, 0·141 in. in diameter, and weighed 126·4 grs. Troy; the magnetising helix was a little longer than the bar. The following Table contains the results of the experiments. A number proportional to the intensity of the current is represented in it by f, and the magnetic moment by m: —

f.	m.
658·9	911·1
1381·5	1424·0
1792·0	1547·9
2151·0	1627·4
2432·8	1680·7
2757·0	1722·7
3090·6	1767·3
3186·0	1787·7
2645·6	1707·9
2232·1	1654·0
1918·7	1584·1
1551·2	1488·9
1133·1	1327·9
670·3	952·0

We have merely to cast the eye over these figures in order to recognise that there is no proportionality between the intensity of the current and the magnetisation; and that, when the intensity increases indefinitely, the magnetisation tends toward a maximum.

which magnetisation tends, possesses, as we shall see, a great importance in the construction of electro-motive machines, since it assigns to their power a limit which cannot be passed over, even though the force of the electric currents should be increased indefinitely.

As we have seen, the intensity of the current, although the most important, is not the only circumstance that influences the power of electro-magnets. The diameter of the bars, according to M. Dub, increases their power in a relation which, within certain limits at least, is that of these diameters themselves. We have already referred to what concerns lengths. With regard to mass, it appears that it exercises no very sensible influence; for, according to M. Haldat, a cylinder of hollow iron acquires, under the influence of the same helix, traversed by the same current, as much magnetism as a solid cylinder of the same diameter and the same length. This result, which has been verified in a very great number of cases, is generally admitted; and it has enabled us in many cases to diminish the mass of the apparatus in which electro-magnets are employed, without in any degree reducing their power.

But one of the points which, circumstances being similar, has the greatest influence over electro-motor apparatus, is the nature of the soft iron that is employed, and its aptitude to acquire and to lose its magnetism promptly; or to acquire successively inverse magnetic poles. As far as concerns this point, there is no rule to give, except that it is preferable to employ old iron, prepared with wood, and to have it annealed a very great number of times.

Electro-motors are machines in which the motive power is an electro-magnetic force, that is to say, that they are all founded upon the existence of a force susceptible of being destroyed instantaneously by a physical and non-mechanical cause. For, in the same manner as a jet of cold water brings about a condensation of the steam, whose elastic force raises the piston in the cylinder of a steam engine, every electro-magnetic apparatus loses its properties from the moment that the electric current no longer circulates in it; we, therefore,

conceive the possibility of giving rise either to an oscillating motion or to continuous movement of rotation, by impulses arising from actions that cease when the mass subject to the impulse has traversed the field of force; and we, at the same time, see the essential difference which, in a mechanical point of view, separates electro-magnetic phenomena from the magnetic properties of permanent magnets.

We are first about to study electro-motors, in which the action of electro-magnets has been turned to useful account; and we will then describe some apparatus which depend upon the attraction that is exercised by a helix over soft iron. In the chronological order, the first machine to mention is that of Dal Negro, who conceived the idea of causing an ordinary magnet to oscillate between the two poles of an electro-magnet which changed polarity at each oscillation; this oscillating movement was easily transformed into a continuous movement of rotation. Since Dal Negro's time, a great number of apparatus have been devised operating either in the same manner, or by the see-saw motion of soft iron armatures, attracted by electro-magnets, then falling back by their own weight; but M. Jacobi is the first who constructed an electro-motor in which the primitive movement was a continuous movement of rotation; and by very simple mechanical considerations he showed that every arrangement, in which the attractive or repulsive power of the electro-magnetic masses produces an oscillating movement, is contrary to the mode of action of electro-magnetism. We know, in fact, that in a machine the increase of the motive force, or of the power, gives rise to an increase of velocity, if the resistance remains constant, and that this increase of velocity produces, what is termed, *vis viva*, and may then be turned into useful work. Now, the attraction that is exercised by an electro-magnet is a function of the distance, the form of which is not exactly known; but which is such that the attractive force increases rapidly, when the distance diminishes, and that it is at its maximum at contact. It follows from this that, in an oscillating apparatus, the velocity, and consequently the *vis*

viva of the attracted mass are the greatest, at the very moment when they are necessarily destroyed; since the motion changes in direction; so that a considerable portion of the *vis viva*, developed by the electro-magnetic action, is destroyed in pure loss by a shock. M. Jacobi adds that it was for a long time thus for steam, which became a really useful motor only from the day when Watt applied the expansive principle, that is to say, allowed the piston to arrive at the extremity of its course with a velocity almost null. It clearly follows from these considerations, that, in every electro-motor, in which the utilised force is derived from an electro-magnet, a continuous circular primitive movement is the only one to employ, which induces us not to devote ourselves to describing the various oscillating apparatus that have been devised.

We give here (*fig.* 365.) the figure of Jacobi's electro-motor. Four horse-shoe electro-magnets are arranged horizontally against a vertical disc, movable around an axis *a*, opposite to four others, placed upon a fixed frame, in such a manner that the poles of the former may come exactly opposite to, and at the smallest possible distance from, the poles of the fixed electro-magnets. The same current passes simultaneously in all the helices; it always maintains the same direction in the system of the fixed electro-magnets; but it is able to change in direction in the system of movable electro-magnets. Suppose, indeed, a movable pole to be placed near to a fixed pole of the contrary name, there is attraction; but, from the moment when they are opposite to each other, if the attraction remains, the onward impulse will be destroyed; if, on the contrary, by the inversion of the current in the movable pole, they become poles of the same name, at the moment when they are opposite to each other, they repel each other, and a new impulse is given in the same direction as the preceding; what we have been analysing for one movable pole must take place for all, and whenever each of them shall pass before a fixed pole. The change of polarity is, therefore, an object of the highest importance; it must be brought about instantaneously; and, for this purpose, is em-

ployed the part of the machine called a commutator, which we shall find in all electro-motors, under forms more or

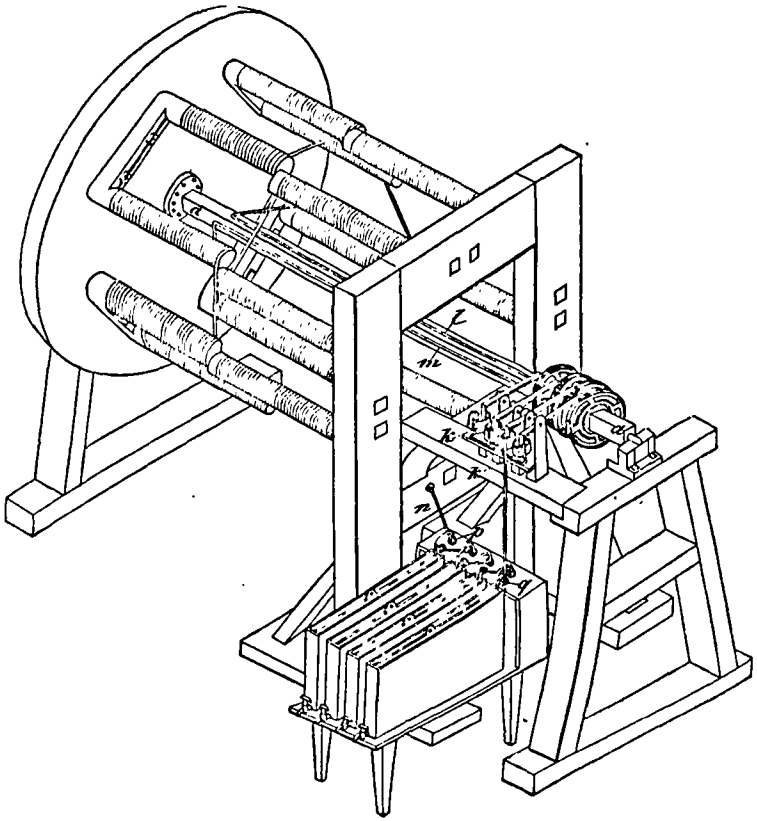

Fig. 365.

less ingenious. It is here composed of four copper discs, fixed upon the axis of the machine, and the circumferences of which carry four sectors of ebony equally distributed. The two middle discs are insulated from each other; and each is connected to the neighbouring disc by a copper tube, separated from the axis by an insulating body. Four copper bars, in the form of a lever, rest on the one hand upon the discs, and terminate on the other hand by rods, bent at right-angles, which plunge into cups *k*, containing

mercury, the two extremes of which, as well as the two middles, are joined together by conductors. The wire that surrounds the fixed electro-magnets has one of its extremities at the pole *p* of the pile, the other end in the cup nearest to the body of the machine; that which surrounds the movable electro-magnets communicates by the wires *l* and *m* with the two pairs of discs, which move with it; finally, the second pole *q* of the pile is connected with one of the middle cups. It is easy now to comprehend how the current passes sometimes in one direction, sometimes in the other, through the conductor which surrounds the movable electro-magnets, according as a sector of wood or ebony arrives in contact with a lever upon one or other of the discs, by the fact of the rotation of the axis; and to comprehend how the discs may be arranged so as to accomplish the inversion of the current for the given positions of the movable poles. We have described the arrangement adopted by M. Jacobi in the first apparatus that he constructed; but the arrangement of the electro-magnets admits of the greatest variety, provided it be exactly symmetrical in respect to the axis, and that it allows the poles to encounter each other as nearly as possible. In order that the action may not be too oblique, in respect to the direction of the movement, seeing that the centre of magnetic attraction is situated at a certain distance from the extremity of the bars, it would be more convenient to arrange the axes of the movable cylinders of soft iron perpendicularly to those of the fixed soft irons. A certain number of apparatus, founded upon the same principle, have been constructed since that of M. Jacobi, among others that of M. Lbiseau, in which the current does not pass through the electro-magnets that are to act upon each other, until the latter are at a feeble distance, an arrangement which in the best manner turns to useful account the force developed by the current.

Apparatus have also been constructed, in which the action of electro-magnets upon permanent magnets is employed; and we may cite an electro-motor, invented by Mr. Davenport, and put into use in New York. Two small horizontal electro-magnets, placed across, and movable around a vertical

axis, revolve in the interior of a circle also horizontal, formed by two magnets, bent into semi-circles, and whose poles of contrary names face each other. The action of the apparatus is easy of comprehension; the extremities of the electro-magnets, which change polarity by means of a commutator, are attracted, then repelled, by the poles of the magnets.

We now arrive at electro-motors, founded upon the attraction that is exercised by an electro-magnet upon an armature of soft iron, and which appear to be more advantageous than those which we have previously described; without its being possible to establish in a precise manner the causes of their superiority, we may yet give some reasons for it. Indeed, in this system, there is no longer any change of polarity, but only discontinuous magnetisation always in the same direction, which requires a much less complicated commutator, and one that is able to act with more regularity; in the second place, it seems probable that this simple alternative of magnetisation and demagnetisation, permits of a more energetic development of magnetism, than does a continual change of polarity; finally, it may happen that the repulsive power of two electro-magnets of different dimensions is changed into an attractive power, the more feeble of the two being nothing more than a soft iron in respect to the more powerful, and, we conceive, without the repulsion being completely destroyed, that it may, by the same cause, be diminished.

Fig. 366. represents an electro-motor, constructed by M. Froment, under very good conditions. It is composed of four fixed electro-magnets, supported by a cast-iron frame M, N, in which the same current circulates in turns. Eight soft iron armatures are arranged upon a movable wheel; when an armature arrives near to the pole of an electro-magnet, the latter is magnetised; then this magnetisation ceases at the moment when the attracted piece of soft iron is situated opposite to it: the wheel thus receives a series of impulses, which bring about a rapid movement; the following is the manner in which the distribution of the current is brought

about. Upon a semi-circle of copper, fixed to the cast-iron frame, around the axis of the apparatus, are arranged

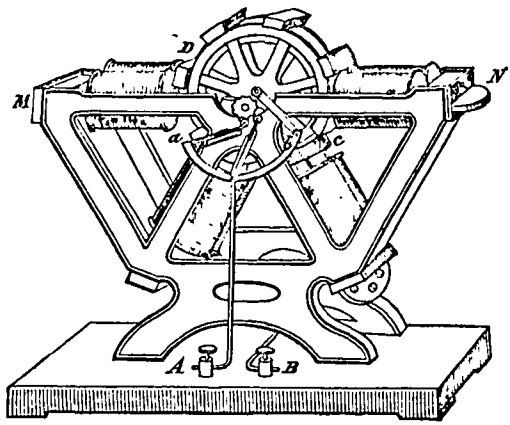

Fig. 366.

three rolling commutators, one of which is figured separately (*fig.* 367.) It is composed of two metal plates *g d*, and

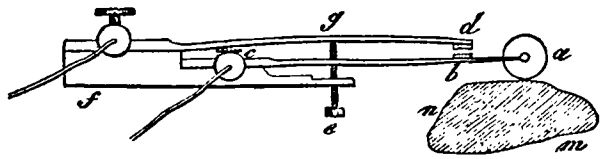

Fig. 367.

c b, between which there is electric communication, only when, the wheel *a* being raised, the two small cylinders *d* and *b* come into contact. If, therefore, the former of these two plates communicates always with one of the poles of the pile, by the intervention of the copper semi-circle, and the latter with the wire of an electro-magnet, which, by its other extremity, is connected with the other pole of the pile, we see that the current will pass through the helix, as soon as the wheel is raised, and will cease passing as soon as it falls back; now, it is the teeth of a little wheel, fixed upon the axis of the machine, which raise in turn the wheels of the commutators, two of which correspond to the two extreme electro-magnets, whilst the third is in connection with the two lower electro-magnets, which are

always found in the same conditions. Magnetisation takes place only when the armature is very near to the poles; and we may conceive that it does not last long, since the four electro-magnets are successively magnetised in the interval of time that elapses between the passing of two successive armatures before a same pole. When an electro-motor is in action, every time the current ceases to pass in a helix, or, which comes to the same thing, changes its direction in it (since, in order to change its direction, it must necessarily cease for an instant), there is produced an extra current, and, consequently, a spark at the place of the interruption; this spark possesses the very grave inconvenience of oxidising the contacts of the commutators, and rapidly bringing about irregularities in the action of the apparatus. M. Froment has succeeded in diminishing considerably the intensity of the spark, due to the extra current, by so arranging the commutators, that the current commences to pass into the neighbouring conductor, before it ceases in the circuit, in which it is travelling. In this way the current is diminished one half, at the moment when it is interrupted, which so much reduces the induction spark, that it ends by disappearing, on applying this method to apparatus, furnished with a considerable number of electro-magnets.

M. Froment and other philosophers, have constructed a very great number of electro-motors, differing from this one, that we have been describing, only by their dimensions, or by modifications of little importance. In all these apparatus, the armatures pass before the electro-magnets, following a line perpendicular to their axes; and remain consequently always at a greater or less distance from their poles. Now, as the attractive power, due to electro-magnetism, increases rapidly when the distance diminishes, we do not thus turn to useful account all the force, which the electro-magnets, that are in operation, are capable of developing. It was therefore interesting to find an arrangement such that the electro-magnet and the armature might come into contact, still avoiding the shock, and the inconveniences of the oscillating apparatus; with this view MM. Wheatstone, Froment, and

Marié have devised electro-motors, in which a wheel, furnished at its circumference with armatures or with electro-magnets, rolls against the interior surface of a circle, tangent to the poles of electro-magnets, fixed and arranged symmetrically all around. The movable wheel imparts a movement of rotation to the axis of the machine, which passes through the centre of the fixed circle; and advantage is thus taken of the magnetic action up to the point of contact of the magnetised masses.

M. Larmanjeat has arrived at a more advantageous result by a different arrangement; and his apparatus, of which M. Becquerel has given the description, is arranged in the following manner; the armatures are cylinders of soft iron, M, able to turn around their axes, which are fixed, and are placed parallel to each other, so as to form a cylinder, about a yard in length, the transverse section of which is represented by the left part of *fig.* 368.; three electro-

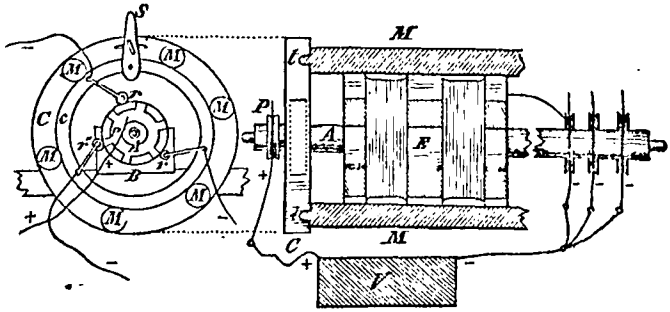

Fig. 368.

magnets, arranged one after the other, are movable around their common axis A, which is also the axis of the cylindrical figure, formed by the armatures. The right part of the same figure represents one of these electro-magnets, which is composed of a bar of soft iron, furnished with three discs E, perpendicular to its axis, and separated by two helices, which thus constitute a double circular electro-magnet; these iron discs are tangent to the cylinders of soft iron which, by their mobility around their respective axes, oppose no obstacle to their movement of rotation, even when

in contact with them, and their circumferences present six sectors in copper, equally distributed; when an iron sector arrives near to an armature, the current passes in the helices, there is produced an attraction, which lasts till the moment when the iron part of the circumference of the disc is found to be placed symmetrically on either side of the point of contact; at this moment, the magnetisation ceases, then recommences for another sector of iron, and so on. The lines of separation of the copper and iron sectors upon the three electro-magnets form a helix, which causes each armature to be continually in action upon one of its points. We have nothing special to say concerning the commutator represented in the figure, the mechanism of which offers here no peculiarity.

We have thus passed in review the principal electro-motors founded upon the attractive or repulsive power of electro-magnets; and it remains for us, in order to complete this succinct description, to say a few words upon the apparatus, founded upon the action that a helix exercises upon soft iron; we may indeed call to mind that, if a cylinder of soft iron is presented before the opening of a helix, in which a current is circulating, it is immediately drawn onward, and does not stop until it is placed symmetrically in respect to the middle of the helix. We can conceive that this electro-magnetic action may be turned to useful account as a motive force; for, according to what we have just seen, it is able to furnish to the mass of soft iron a considerable range; but we see that it is impossible that it can give rise to a primitive circular movement, whilst it gives rise very naturally to a backward and forward movement. Besides, it is probable that the objections, which M. Jacobi has made to oscillating apparatus, do not apply in this case, at least with so much rigour; for it seems natural to believe that the force, with which the soft iron is drawn into the helix, diminishes, in proportion as it is buried in it; since it ends by becoming null.

Fig. 369. represents Mr. Page's electro-motor: it is composed of two bobbins, fixed horizontally, in such a manner

that their axes are in the prolongation of each other; two cylinders of soft iron, joined by a copper rod, are connected to a system of slides, which allows them to oscillate parallel to the axis of the bobbins, and which is articulated to a crank, by means of which the backward and forward movement is transformed into a circular movement. The current passes into the former helix; the corresponding soft iron buries itself in it, which causes the sec nd soft iron, to come out of the second helix; by the intervention of a commutator, the current then passes from the first to the second bobbin, which in its turn acts upon the cylinder of soft iron, that corresponds to it; and we thus see how the backward and forward movement of the mobile system is produced. We are indebted to M. Dumoncel for an analogous apparatus, in which the bobbins themselves are able to oscillate as do the cylinders of oscillating steam engines, which enables us to articulate the rod, that is connected with the soft iron, directly with the crank of a wheel.

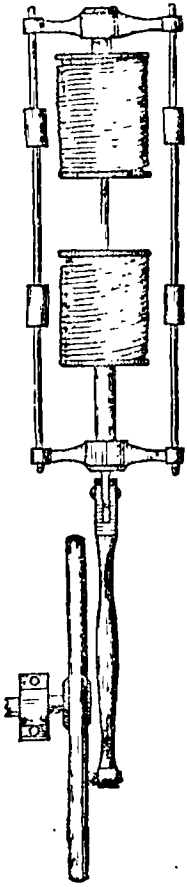

Fig. 369.

After having studied the principal electro-motors exclusively in a mechanical point of view, that is to say, by taking account merely of the arrangement of these apparatus and of the advantages or the inconveniences, which they present, in order to utilise the forces, that are developed in them by dynamic electr city, it is interesting to enter more deeply into the question; to analyse what takes place, when one of these machines is in motion; and finally to compare, with regard to useful effect, the electro-magnetic forces with the other motive forces. We are indebted to M. Jacobi for the greater portion of the accurate and really scientific notions, that have been acquired upon the theory of electro-motors. It was necessary indeed

to know, first the laws of electro-magnets, that is to say, the manner in which their magnetism varies, both with the nature of the helix, that is to say, the number of its convolutions, and the size of its wire, as well as with the form itself, the length and the thickness of the soft irons; now, here, as we have seen, is the subject of the researches of MM. Lenz and Jacobi, who have arrived at laws, if not very general, at least approximately true within wide limits. But there remained another element of the question to be elucidated. Let us consider an electro-motor in motion, that of M. Jacobi, for example, executing no useful work, and consequently only having to overcome the resistance of the air, and that which is due to the various frictions of the machine; the commutator renders the changes of polarity instantaneous, whatever may be the rapidity of the motion; we assume that the electro-magnet excitation of the soft iron is also produced in an instantaneous manner; and finally that the attraction or repulsion of the magnetic masses is independent of their relative velocities. We are, therefore, in presence of a constant force, that should produce an accelerated motion, which friction will not be able to render uniform, since it is independent of the velocity; but only the resistance of the air, which increases with it, will. Now, it is easy, setting out from this hypothesis, to calculate approximately the velocity with which the apparatus will be animated, when the motion shall have become uniform; and we find, that it is much greater than the limit of velocity, that cannot be exceeded. It was therefore, in the motive force tself, that it was necessary to seek for the cause of this limit; and, setting out from these mechanical considerations, M. Jacobi has clearly established the influence of induction. Indeed every electro-motor in motion acts, at the same time, as a magneto-electric machine; independently of the extra currents, that are developed by the induction of the helices upon themselves, and which arise from the motion, only because the motion of the apparatus causes the commutator to act, induction currents are created; or, if we prefer it, tend to be created

in the helices, that are approaching to, or that are receding from each other; and these currents, according to Faraday, travel in directions contrary to those that are produced by magnetisation. There is necessarily, therefore, a diminution in the intensity of the magnetising currents, — a diminution, which is greater, in proportion as the motion is more rapid. Hence, we see how the increase of velocity produces a diminution of the motive force; and how, when the moment arrives, in which this force is precisely equal to the passive resistances of the machine, the motion becomes uniform. Thus when a galvanometer is interposed in the circuit, so long as the electro-motor is prevented from acting, the needle is deviated to a constant angle; but, as soon as the motion commences, the deviation of the needle diminishes; and, it does not cease to diminish until the motion has become uniform. We may therefore say, that motion introduces into the circuit a resistance, that goes on increasing when it is accelerated; however, we must not omit to remark that there is here no real loss of force, since the zinc consumed remains always proportional to the intensity of the current; but merely simultaneous reductions of the expense and of the force put in play.

Setting out from the laws of electro-magnets already given, from those which are recognised for induction currents, and finally from Ohm's general laws, M. Jacobi has been able to submit to calculation the theory of electro-motive machines.* Among the results, to which he has arrived, there is one which sums up almost all the others, and of which we shall here speak; it is the expression that he has found for the maximum work, which an electro-motor is susceptible of giving. We know that, in a machine in motion, the motor work is the product of the motive force by the velocity of its point of application; and that moreover, if the motion is uniform, the motor work is equal to the resistant work, which is itself composed of the useful work and the passive resistances of the machine. Electro-motors always enjoy the property of being susceptible of a maximum of useful effect, — a property

* See the final Note G.

in which the greater part of other machines participate, seeing that, among the acting or the resisting forces, there are scarcely any, in which one of them at least does not vary with velocity. Now, in an electro-motor, according to what we have seen, it is the motive force that diminishes when the velocity increases; we understand therefore how the expression of motive work composed of two factors, which vary in contrary directions, must pass through a maximum; and M. Jacobi has found that it attains this, when the velocity is such that the intensity of the current has become the half of what it is, when the apparatus is maintained at rest. But what is most remarkable is that the helices of the electro-magnets do not enter into the expression of this maximum work except by their total resistance; so that, this resistance remaining the same, we may increase or diminish the number of their spirals without introducing the least change into the maximum of the work, but simply by causing its elements, that is to say the force and the velocity, to vary. The arrangement of the conductor upon the bobbins plays here therefore a part analogous to that of an organ of transmission in ordinary machines, that is to say, that on making it suitably to vary, we are able, while still producing the maximum of motor work, to cause the apparatus to act under the conditions of velocity most favourable to the useful work, that we desire to produce. Besides this result possesses this important feature, that it shows the inutility of the attempts that have been made and that might be made for arriving at more advantageous results by giving large dimensions to the electro-magnets. To sum up according to M. Jacobi's theory, the maximum work, that can be obtained with a given pile, varies according to the electro-motor with a co-efficient that depends upon the general arrangement of the apparatus and of the coercive force of the soft iron that is employed in it; it is the value of this co-efficient, which characterises an electro-motor machine; and in describing these machines, we have directed our attention to the circumstance that causes it to vary. Moreover

the electro-motive force of the voltaic combination, employed enters as a factor into the expression of this same maximum work; so that, for an equality of zinc dissolved, a Grove's pile gives $1\frac{3}{4}$ more work than a Daniell's pile; but the relation of the work obtained to the zinc expended is independent of the arrangement of the battery. These results, obtained by M. Jacobi, possess the advantage of throwing light upon the vague notions, that had previously prevailed upon the whole of this theory, and of distinctly establishing which organs of the electro-motor are susceptible of improvement. It is on the one hand, the general arrangement of the apparatus, not including in this summary of various conditions those which are relative to the construction of the electro-magnets; and on the other hand, the electro-motive force of the pile, and not the manner in which it is arranged.

The theory, that Messrs. Joule and Scoresby have given of electro-motors, rests upon the hypothesis of the transformation of heat into mechanical work. Mr. Joule has demonstrated that, if all the heat, developed by the solution of a grain of zinc in Daniell's pile, were utilised, its mechanical power, which is deduced from the mechanical equivalent of heat, would be represented by a weight of 150lbs. raised to the height of a foot. On the other hand, it is admitted that the chemical heat is transformed, both into calorific as well as into mechanical effects in the circuit. Let us now consider an electro-motor, in which the current is circulating, but which is maintained at rest; and let a be the intensity of the current. If the apparatus is allowed to go on, the intensity of the current diminishes and becomes b. The quantities of heat developed in the two cases are to each other as $a^2 : b^2$; but the total work, as well calorific as mechanic, must always be in a constant relation with the intensity of the current, or, which comes to the same thing, with the quantity of zinc consumed. It is therefore necessary that, in the latter case, the quantity x of mechanical work shall be such, that we have:

$$b^2 + x : b = a^2 : a;$$

since, in the former case, the calorific work was the total

work; the relation of the mechanical work to the total work is expressed by

$$\frac{x}{b^2+x};$$

and we find

$$\frac{x}{b^2+x}=\frac{a-b}{a}.$$

Now, we know that one grain of zinc consumed would give, if it were entirely utilised, a work represented by 158; it will therefore give here:

$$158\left(\frac{a-b}{a}\right)$$

Messrs. Joule and Scoresby have applied the formula to a very great number of experiments. They found, as a mean with their apparatus a theoretical work, deduced from their formula, of 78lbs. 5oz. per grain of zinc; and that, which they really obtained, only reaches 65lbs. 6 oz. per grain; so that the effective work must be considered, according to them, as equal to $\frac{4}{5}$ of the theoretical work, under the conditions in which they were placed.

This theory of electro-motors, which is evidently unable to throw any light upon the improvements to be introduced into these machines, and which simply expresses the transformation of the heat, developed by a chemical action, into mechanical work, enables us to compare immediately, under the relation of their utility, electro-motive machines with steam-engines; for in these latter, it is also the heat, liberated by a chemical action, that is transformed into a mechanical work. The calculations of Messrs. Scoresby and Joule, and the results already obtained by Oersted, and since by Mr. Hunt, very nearly indeed agree; a grain of coal consumed in the furnace of a Cornish engine, has raised 143lbs. one foot, whilst a grain of zinc consumed in a voltaic battery can raise theoretically only 80lbs. The price of a hundredweight of coal is less than 9 pence, whilst that of a hundredweight of zinc is more than 216 pence; whence it would result that, under the best conditions, the magnetic force is 25 times dearer than that of steam.

Researches have been made on this subject by M. E.

Becquerel, with the view of proving before the jury of the Universal Exposition, the mechanical power and the expense of some electro-motors; the following are the results, as they have been stated by M. Becquerel himself.

Nature of the Electro-motor.	State of the Pile.		Work of the motor without the voltameter.	Work of the motor with the voltameter.	Consumption of zinc per hour and per lb. raised one foot.	Consumption of zinc per hour and per horse power.
	Number of Elements.	Total surface of zinc of each element.				
		sq. in.	lbs. raised 1 foot.	lbs. raised 1 foot.	grains.	lbs.
ROTATING APPARATUS:—						
Larmanjeat's apparatus, armatures turning upon the electro-magnets	20 single, zinc interior	13·17	6·032	5·195	342·2	26.46
"	10 double "	26·35	—	3·492	434·2	33·51
"	10 triple "	39·52	7·418	6·494	128·3	9·92
"	10 quadruple "	52·70	9·236	6·927	130·4	10·08
Loiseau's apparatus, similar to that of M. Jacobi.	10 quadruple	52·70	18·132	6·227	293·0	22·60
OSCILLATING MACHINES:—						
Roux apparatus	10 triple	39·52	5·982	4·055	372·1	28·77
"	10 single	13·17	—	3·247	303·7	23·54
"	10 double	26·35	7·591	4·214	308·0	23·81
"	10 triple	39·52	11·184	6·133	282·3	21·82
"	10 quadruple	52·70	26·410	10·824	169·7	14·64
"	8 " zinc exterior	325·50	11·544	9·597	94·1	7·27
"	6 " "	325·50	4·329	2·994	61·8	4·85
Favre and Kunemann's apparatus	24 single, zinc interior	13·17	—	3·694	—	—
"	12 double "	"	3·088	—	—	—
"	12 " "	"	2·960	—	—	—
"	12 " "	"	—	1·630	902·6	69·89

We shall merely remark that M. Becquerel does not appear to have concerned himself with making the different apparatus work, so as to make each of them give the maximum of work, which would have been an important element in the determination of their relative values. The four apparatus were chosen, which, from their dimensions, allowed of the dynamometric check being adopted with them. These apparatus were: 1st, a machine, constructed by M. Larmanjeat, and already referred to above; 2nd, a machine constructed by M. Loiseau, and analogous to M. Jacobi's rotating machine, with this difference, that the currents, by aid of a distributor, pass into the electro-magnets in presence only when they are at a little distance from each other; 3rd, of an oscillating machine devised by M. Roux, and in which

plates of iron successively approach and recede from fixed and vertical electro-magnets, but so arranged as to utilise the magnetic action of the wire of the electro-magnets upon an exterior armature of soft iron; these electro-magnets are of the form of those, which M. Nicklès has termed trifurcate; the plates of soft iron have a backward and forward movement, which is transmitted to an arbor, and gives a continuous rotatory motion; 4th, finally, an oscillating machine, constructed by MM. Favre and Kunemann. The quantity of work was given by the aid of a dynamometric check. In order to know the expense in electricity, the electric current circulating in the machine, is made to pass to a sulphate of copper voltameter; the salt was decomposed, and the metallic copper was precipitated at the negative pole, whilst the positive electrode was consumed. There was a small difference between the weight of the deposit at the — pole, and the loss of weight at the + pole; but, for experiments of this nature, it is insignificant; and the mean of the two determinations are taken. Now, as in each element of the pile, the chemical work is the same as in the voltameter, it is therefore easy to estimate the value of the quantity of zinc, dissolved in each pair, from the quantity of copper, deposited in the voltameter; on multiplying this number by the number of the elements of the pile, the total consumption of zinc is deduced from it. We may therefore, in a given time, obtain by this method both the quantity of work given by the check (column 5 of the above Table) and the expenses indicated by the consumption of zinc (column 6 of the Table). The elements of the pile employed, except in the last two, made with the Roux apparatus, were Bunsen's elements of a small dimension, having porous vases of 5 inches in height, and 2 inches in diameter.

Application to Telegraphy.

We have seen, in the preceding paragraph, the attempts that have been made in order to apply the magnetic properties of the electric current to the construction of a mechanical motor. In respect to economy and power, this motor is very inferior to those that are commonly employed, and

to steam in particular; but it possesses a special character, which renders it suitable for purposes, to which it alone is able to be adapted. The characteristic difference is the unlimited distance, at which it is able to act. It is, as it were an arm, which possesses the power of being indefinitely lengthened, in order to carry the hand wherever there is an action to be exercised. Wheresoever, then, a great force will not be indispensable, and when there will be the necessity of acting instantaneously at a greater or less distance from the place, whence the action is to set out, the magnetic power of the electric current will become one of the most valuable forces, that nature is able to present to us.

Before having known the magnetic power of the electric current, a great number of philosophers had put forth the idea of applying to telegraphy the property, that is possessed by electricity, of propagating itself instantaneously from one extremity to the other of an insulated conductor. A learned Scotchman whose name is only known by the initials G. M., and George Louis Lesage, at Geneva, had each in their turn devised telegraphic systems which would act by means of an electric machine. But the inconveniences that result from this mode of the production of electricity, which is always more or less uncertain, and the complication of the means proposed, rendered fruitless the numerous trials that were made from 1787 to 1813. However Soemmering, in 1811, had conceived the construction of a telegraph founded upon the property of the voltaic current of decomposing water; but the very great number of electric circuits, that such a system required, since so many signals were necessary, rendered it scarcely practicable; moreover, the indications required a certain time for manifesting themselves. This latter inconvenience was avoided in the system proposed by Ampère, in 1820, after Oersted's discovery, which consisted in employing the instantaneous action, that is exercised upon the magnetised needle by the current; but the first inconvenience, that of the considerable number of circuits necessary, still remained. However, Messrs. Ritchie and Alexander constructed at Edinburgh, in 1837, a telegraph, which was the realisation of Ampère's system; only, sup-

posing that twenty-four signals were required, instead of 48 conductors they erected only 25; one alone being sufficient for the return of the currents transmitted by the 24 others. Fechner had proposed, in order to render the effect more sensible without entailing the necessity of increasing beyond measure the force of the pile, of employing the galvanometer-multipliers, and having as many of them as there are signals to transmit; he had besides clearly anticipated the full extent of this mode of communication.

Schelling was the first, who conceived the happy idea that it was not indispensable to have as many conductors as there are signals; and he showed that, with a single multiplier, a great number of signals might be transmitted, by properly combining the deviations of the magnetised needle, which could take place, now to the right, now to the left, so that a deviation to the left, a deviation to the right, two consecutive deviations to the left, two to the right, two consecutive deviations, but the first to the left, the second to the right, two still consecutive, but the first to the right, the second to the left, &c. &c., represented conventional signs. In order to prevent the needle being too violently shaken by these sudden deviations, Schelling fixed to it a small appendix, which, by plunging into a cup of mercury, deadened the shakings which the needle would have undergone. He also added a kind of alarum to his apparatus, in order that the ear might be forewarned of the commencement of the observation; with this view, things were so arranged that the first motion of the needle caused a leaden ball to fall upon a lever, the motion of which detached the detent of an ordinary alarum. Schelling, who made his first trial in Russia, in the presence of the Emperor Alexander, and subsequently of the Emperor Nicholas, was unfortunately unable to realise his system upon a large scale.

An important step was made in 1833, at Göttingen, by Gauss and Weber, by the erection of two copper wires insulated from each other, extended over the houses between the Museum of Natural Philosophy and the Observatory; a circuit, which by being successfully employed for communications, as well as for regulating the clocks, gave them

a glimpse of the possibility of transmitting letters, words, and phrases to great distances. The electric current intended for establishing communication from one station to the other was an induction current; the indicating apparatus was a simple galvanometer-multiplier, the wire of which was placed in communication, by its two extremities, with those of the wire of the induction bobbin. By means of a commutator, the induction current might be directed in one direction or in the other, so as to obtain the opposite deviations of the needle of the multiplier. By combining in an ingenious manner several movements of the needle, Gauss and Weber succeeded in producing by means of its deviation sometimes to the left, sometimes to the right, all possible signs, both letters, as well as figures. By supposing that, in order to represent a sign, we should go as far as to five deviations of the needle, we at once obtain a means of obtaining 62 different signs. In order to deaden the oscillations of the needle, Gauss conceived the idea of placing the magnetised needle in a copper cage, which he called *the damper*, — a process, founded upon induction and employed subsequently, as we have already seen, by Weber in the construction of the galvanometer.

The apparatus of Göttingen had been established exclusively in a scientific point of view. M. Steinheil of Munich, upon the invitation of MM. Gauss and Weber, endeavoured to simplify them, in order to render them more suitable for the transmission of signs. The changes which he introduced into the telegraph that he established in 1837 at Munich, upon the invitation of the King of Bavaria, were the following: —

1st. He substituted for the induction bobbin of the Göttingen apparatus, a simple Clark's machine, in order to develope the induced currents.

2nd. He formed his indicator apparatus of two magnets, each placed in a multiplier, instead of one alone, so as to obtain a double movement with a single current.

3rd. He furnished the extremities of the magnetised needles with slight appendices of brass, carrying small cups filled with printing-ink, and terminated by capillary points,

which at each movement of the needles upon a band of paper, that was regularly unrolled, by means of a clock-work motion, traced points one after the other in a conventional manner, in order to represent the various letters of the alphabet.

In order to obtain signs sensible to the ear, M. Steinheil had fixed to the extremities of the magnets, instead of cups, small hammers, which approached and struck upon one or other of two bells, having a different sound, and which were substituted for the band of paper.

Gauss had conceived the idea that the two rails of a railway might be employed as conductors of the current for the electric telegraph. Steinheil, having made some experiments, with a view of realising Gauss's idea upon the railroad from Nuremberg to Fürth, was unable to obtain an insulation of the rails, sufficiently perfect for the current to reach from one station to the other; the great conductibility, with which on this occasion he remarked that the earth was endowed, caused him to presume that it would be possible to employ it as a conductor, which would enable us to dispense with one of the conducting wires between two stations. The trials that he made in order to prove the accuracy of this conclusion, were followed by perfect success; and he then introduced into electric telegraphy one of its greatest improvements, both on account of the economy that would be produced by the suppression of one of the conducting wires, as well as by the facility that would result from it, for the establishment of great telegraphic lines.

The transmission of electricity by the earth had already been obtained by a great number of philosophers, of which we have given examples in the First Volume of this Treatise; but M. Steinheil was the first, who proved this fact for voltaic electricity, and with the view of its application to telegraphy. The conductor of the telegraph, constructed at Munich in 1837, was formed of a copper wire, terminated at its two extremities by two plates of copper buried in the earth; the current traversed this distance with the greater facility, in proportion as the surface of the buried plates was increased. Mr. Bain in 1842, made a great number of

experiments upon the conductibility of the ground, chiefly with a view of employing the earth as a moist conduction interposed between the zinc and copper plates of a pair*; he satisfied himself that a tolerably strong and very constant current was thus obtained. We shall see further on that he succeeded in employing this current in order to make electric clocks go. Mr. Wheatstone made also at very nearly the same period a great number of experiments upon the same subject, by studying the propagation of the current through the water of the Thames.

We shall return to the researches, relative to the conductibility of the earth, when we shall be engaged in a more special manner with conductors intended for transmitting a despatch from one station to another; we shall confine ourselves for the present to pointing it out, seeing that we shall very speedily be called upon to point out all the advantages that may be derived from it.

The philosopher, who was the first to contribute by his labours, as ingenious as they were persevering, in giving to electric telegraphy the practical character that it now possesses, is without any doubt, Mr. Wheatstone. This illustrious philosopher was led to this beautiful result by the researches that he had made in 1834 upon the velocity of electricity,—researches in which he had employed insulated wires of several miles in length, and which had demonstrated to him the possibility of making voltaic and magneto-electric currents to pass through circuits of this length. It was in 1837, in the month of June, that Mr. Wheatstone took out his first patent. He first employed five conducting wires between two distant stations acting upon five magnetised needles, the movements of which, being combined two and two, were enabled to produce several different signs. Mr. Wheatstone, at this time, entered into partnership with Mr. Cooke, who had likewise devised an ingenious telegraphic apparatus founded upon the same principles. The

* M. Gauss had before this, observed the appearance of an electric current in a wire placed in communication with the ground, by large metal surfaces fixed at its extremities.

English philosophers from the very first, had added to the telegraph, properly so called, an apparatus, intended to call the attention of the observers, and designated under the name of *alarum*. It is a bell that sounds under a hammer, the detent of which is suddenly released by the action of a temporary magnet of soft iron, upon which the electric current is made to act. Here the current no longer acts in an immediate manner, in order to produce the motion; but it is confined to magnetising by its passage a piece of soft iron; this temporary magnet attracts another small piece also of soft iron, which prevented the action of a permanent spring; the scapement thus becomes free; and a clock movement causes the hammer to move which strikes the bell. Great service has been likewise derived from this very ingenious process for telegraphy itself. The principle upon which it is founded, includes an immense number of applications; for it enables man to put in action at any distance whatever all the forces of mechanics, in an instantaneous manner. Indeed, more recently Mr. Wheatstone applied it to the construction of his dial telegraph; and it is this same principle, which serves as the basis of Morse's telegraph, invented at nearly the same period.

Before passing on to the detailed study of those telegraphs, the merits of which have been sanctioned by practice, and which are universally adopted, we will just quote the electro-physiological telegraph of M. Vorsellemann de Heer, founded upon the employment of the shocks, which the passage of the current brings about in one or other of the ten fingers of an observer; the latter, at a given signal, must place the fingers of both his hands upon the ten keys of a finger board, which, by means of ten wires, communicate with the keys of another finger-board, upon which a second observer makes his fingers to act. The observer, who transmits the signals, takes the precaution of protecting his fingers with gloves, in order not to receive the shock, which is to be detected only by the other observer. The advantage of this system is to require the employment merely of fine wires; but ten are necessary, which is a great inconveni-

ence; but there is also another, which is that the force of the current employed for transmitting the signals, must necessarily vary with the sensibility of the observer who receives them.

We are about to pass on to the examination of the principal electric telegraphs, dwelling upon those only, which are now in use upon the principal telegraphic lines. We may first remark that, in every telegraphic system, there are three distinct parts: the apparatus intended for transmitting and registering the despatches, or the telegraphic apparatus properly so called; —the conductors intended for establishing the desired communications between the *transmitting* and the *receiving* apparatus; — and finally the instruments producing the electricity, which are most commonly voltaic piles, and in some cases magneto-electric induction machines, after the manner of those of Clark. We shall not dwell in a special manner upon this latter point, which we have sufficiently treated upon in our two former Volumes; we shall confine ourselves to mentioning, in reference to each telegraphic system, that we shall be called upon to describe, what the apparatus is, that produces the electricity, which is employed to set it in action.

We may class under three heads the different telegraphic systems, that are most in use; the first comprises the telegraphs founded upon the deviating action, that is exercised by the current upon the magnetised needle; these are the needle telegraphs: the second includes the telegraphs, in which the action of the current, by magnetising a piece of soft iron, causes an index, such as a needle, to move on, intended to point to the sign that we desire to transmit; these are essentially the dial-telegraphs; we may place under the third head, the telegraphs, in which the action likewise takes place by means of the magnetisation of soft iron by the current, but in which this action is exercised upon apparatus, by means of which the despatches are registered, so that there remains a permanent trace. Of these three systems, the first and, especially the third, are those which are now most generally diffused; also, being compelled to restrict ourselves, it is of these, that we shall chiefly give a detailed description.

Needle Telegraphs.

The essential part of the needle telegraph is the multiplier (*fig.* 370), the needle of which, fixed vertically upon a horizontal axis, moves in front of a dial. Among these telegraphs, some are single needle, others, and they are the more numerous, are double needle. The single needle telegraph (*fig.* 371.) shows an alphabet, engraphed on the right and left of the needle; some letters require as many as four movements, which may be either all on the same side, or some on one side and some on the other; but it is necessary, that the last movement of a letter, placed on the right, shall be always to the right, and that of a letter placed to the left, always to the left. Thus W, is indicated by four movements, three to the left, and the fourth to the right; L by four movements, to the right, to the left, to the right, to the left. Beneath each letter, there is a sign, formed of one or more right lines, inclined toward the right or toward the left; some of these diagonal lines are entire, the others have only half the length; the direction of the diagonal is that of the deviation, and one deviation is required for each diagonal; the deviation indicated by the demi-diagonal is first made. In order to simplify the matter, it has been agreed to proceed in the following manner; one, two, three, four deviations to the left are first employed for the first four signals, then one to the right with one, two, three deviations, to the left for the three following signals; then two to the right, with one and two to the left; then three to the right with one to the left; then to the left, the right, the left; and finally to the right and left, the right and left, which leads as far as the letter L; and thus completes the first half of the series. The second half is the counter-part of the first; the deviations to the left are simply replaced by deviations to the right, and reciprocally. The figures are inscribed under the

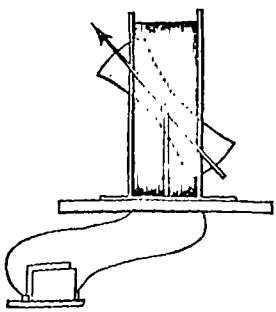

Fig. 370.

needle; and they are indicated by the movements of the lower part. Thus in order to show 4, the lower extremity of the needle is carried once to the right and once to the left.

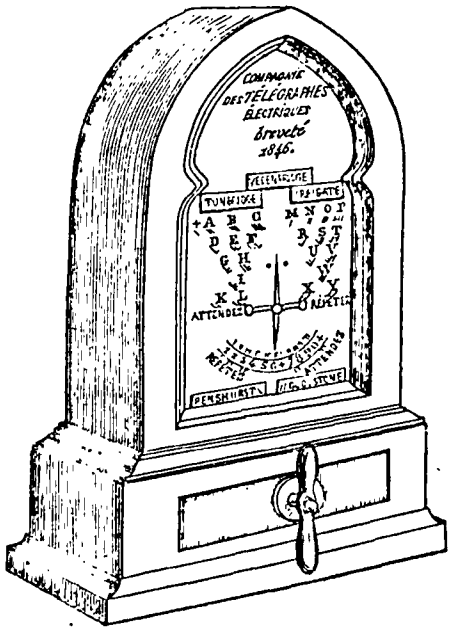

Fig. 371.

The double needle telegraph differs from the preceding only inasmuch as it is composed of two multipliers instead of having but a single one. The two needles are likewise arranged vertically each on a horizontal axis (*fig.* 372.). The upper case is occupied by the bell or alarum. The letters of the alphabet are arranged upon several lines, commencing at the left and finishing at the right, as in ordinary writing. The first series, from A to P, appear above the points of the needles; the second series from R to Y, appears below the points of the needle. Each letter is indicated by *one*, *two*, or *three* movements. The letters of the upper series are formed by the nearest needle, which is made to deviate once, twice, or thrice on the side where the letter is, so as to point towards it. For the letters of the lower series, both needles are moved together, by directing their lower ends towards the letter. Six letters C, D, L, M, U, V,

require two contrary movements of the needle, or of both needles; first to the right, then to the left for C, L, and U;

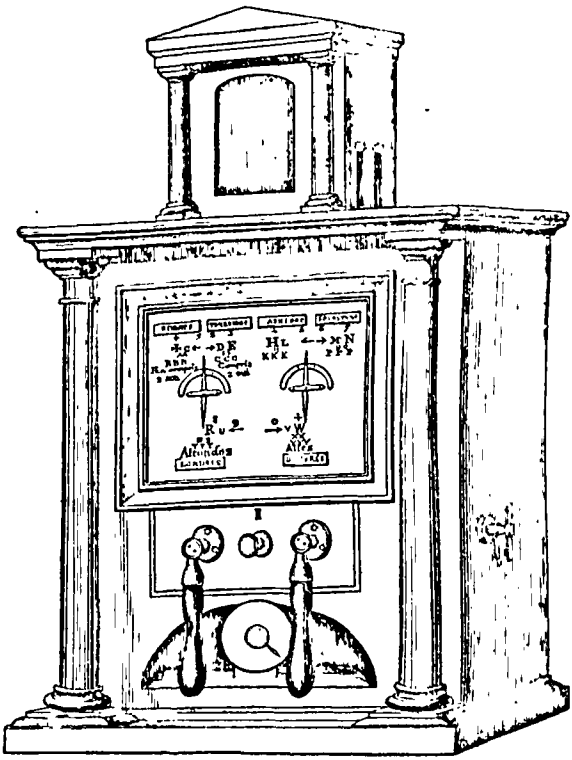

Fig. 372.

and first to the left, then to the right for D, M, and V. These letters are engraved in small capitals and separated by double arrows.

It remains for us now to make known the internal arrangement of the needle telegraph; we shall content ourselves, for the sake of simplicity, with describing that of the single needle telegraph; the arrangement of the double needle telegraph being, with a slight modification, almost perfectly similar. The multiplier, in these telegraphs (*fig.* 373.), carries, as in ordinary multipliers, two needles, the one *a*, called *diamond needle*, when made in the form of a lozenge, very short and very wide; the

other A, exterior, rather longer and similar to ordinary needles. Mr. Walker found the advantage of substituting

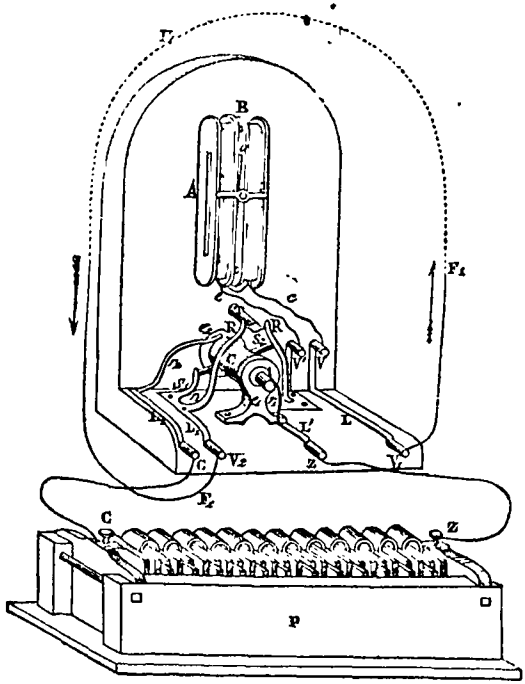

Fig. 373.

for the diamond needle, a needle formed of several very short needles, of thin steel and strongly magnetised, fixed upon an ivory disc of 1¼ in. in diameter (*fig.* 374.). A single narrow coffin-shaped rhomb makes a good needle. The outer needle is 3 inches in length. The frame of the bobbin B (*fig.* 373.) is of brass, or better still of wood or ivory; it is fixed by screws to a brass plate, often varnished on the side towards the case, and supported against its frame; or it is made in halves, and slides into grooves at the back of the case, independent of the dial. The wire of the bobbin is less than a hundredth of an inch in diameter; its two extremities, e, e', abut upon binding screws V, V′; a slip of metal, L, unites the extremity e with another binding screw V_1; e' communicates in like manner, by a metal slip from V′, by the spring R, the stud S_2, the spring R′, with the binding

Fig. 374.

screw V_2. The two slips L, L′ are entirely similar to two others L_1, L_2, which are seen to the left of the figure. The three slips L′, L_1, L_2, communicate metallically by springs R′, R_1, R_2, with a commutator C, the action of which we will soon describe. The springs R′, R_2, which are of steel, press strongly against two points, fixed into a brass stem T, cemented into the wooden case of the instrument. A conducting wire, F, connects the binding screw, V_1, with V_2 (when the instrument is being tried on a short circuit in a room); and the circuit is completed in the following manner between V_1 and V_2:— The current arrived at V_1, passes into the bobbin by the right side, returns by the left, ascends the steel spring R, passes by the studs in the stem to the other spring R′, descends to V_2, and completes the circuit by the wire F. Let us now conceive, that the conducting wire of a first station communicates with V_1, and the wire of the second station with V_2, the apparatus will be in the circuit of the telegraphic line, and quite ready to receive (as above described) the signals manifested by the deviations of the needle or needles; since two similar apparatus are connected up with each other, and their bobbins are traversed at the same time by the current, that goes from V_1 to V_2. In order to obtain greater regularity, it has been agreed, always to place the conducting wire, that leads *up* the line in communication with V_1, and the wire that leads *down* the line with V_2.

The above is the manner in which signals are received; let us now state how they are transmitted. The commutator is a cylinder of box-wood, mounted as shown in the figure, and which is able to turn upon itself by means of a handle; its extremities e_1, e_2, are fitted with brass collars, with studs standing out, and insulated from each other by the wood which separates them. Two strong steel springs r_1, r_2, fixed at the right, and the left upon the brass slips L′, L_2, rest with friction, one upon the brass drum e_1, the other upon the drum e_2, and cause the extremities of the commutator to communicate with the binding screws Z and C, and by their means with the poles of the pile. If the commutator is made to turn, the stud s_2 causes one of the springs R′, R_2,

to rise, which, by this act, will no longer communicate with each other by the stem C. In the figure, it is the right spring R′, that is raised; but a little further motion imparted to the commutator causes the block r', to be touched by the second stud s_2, which places it in communication with the drum e_2; the current of the pile then circulates through the apparatus, and in the whole of the telegraphic circuit. In fact, when arrived at Z, it will pass by r', into the drum e_1, will enter by the upper stud S_2, into the spring R, and thence by V′ into the bobbin, it will come out by V, will come on to V_1, will pass along F_1, into the conducting wire of the telegraphic line, will come to V_2, will pass by L′, to the stud s_1, thence by the drum e_2, and the spring r_2, along the slip to the copper pole C. If the manipulator is turned in the contrary direction, the current transmitted from Z, to the drum e_1, will arrive at V_2, by the spring R, and the plate L_1; will go by F_2, into the conductor of the telegraphic line; will come to V_1, enter into the multipliers by V′, and come by the plate and block to the stud S′, to the drum e, and by the spring r, to the copper pole C. The internal arrangement of the springs of the multipliers is represented (*fig.* 375.) in a

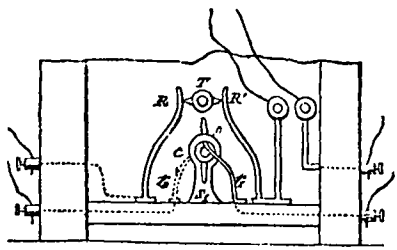

Fig. 375.

manner independent of the rest of the apparatus, which enables us to comprehend it better. The connections are made in such a manner that, when the handle is turned to the right, the needle a, is deviated towards the right. The needle A, placed at the outside of the apparatus, has always its north pole upwards; the inside needle a, has always its north pole downwards; so that, in virtue of the law of the action of currents upon magnets, if on looking at the instru-

ment in front, we see the upper point of the needle move towards the right, we may be sure that in the half of the wire, nearest to the spectator, the current is ascending. We have merely, therefore, to turn the handle, now to the right, now to the left, in order to make all the needles of the telegraphs deviate to the right and left, and transmit signals.

The alarum or bell, intended for giving notice that a despatch is about to be sent, and which is placed upon the top of the case (*fig.* 372.), presents a very simple mechanism (*fig.* 376.); *e*, is an electro-magnet, viewed sideways; *a*, is the movable armature of soft iron, attracted by the electro-magnet every time that, and also for as long a time as, the current passes; two small brass screws, tipped with ivory, and fixed into the armature, prevent its arriving into absolute contact with the poles of the electro-magnet, while still permitting it to approach very near to it. The object of this arrangement is to prevent the adherence of the armature of the electro-magnet; an adherence which too often would continue, even after the rupture of the circuit. The armature is carried by the short arm of the lever *l*, *e*; the other bent arm is terminated by a hook, intended to rest against the teeth of the wheel r_1, in order to lock it, or arrest it in its motion; a weak spring, R, abuts on one side against a fixed obstacle, on the other against the long arm of the lever *l*, constantly tending to bring it, as well as the armature *a*, back to the position of equilibrium. The spring of the clock movement, the principal pieces alone of which are shown in the figure, is contained in the barrel *b*, carrying the toothed wheel r_2; r_3, is a second toothed wheel, the pinion of which is in gear with the wheel r_2; r_4 is a fourth wheel set in motion by the pinion of r_3, in gear with the pinion of the wheel r_1, and in communication with

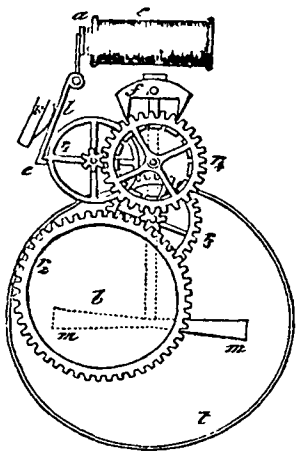

Fig. 376.

the escapement and pallets *f*; finally, a rod fixed to the axis of the escapement is terminated by a double-striking pendulum or two-headed hammer, *m*, *m*. The action of this apparatus is very manifest; when the current passes, the armature *a* is attracted, the lever *l* is carried toward the left, the hook no longer arrests the tooth of the wheel r_1, the action of the spring is no longer prevented, all the wheels turn, and, under the alternate influence of the scape-wheel, the hammer rapidly strikes the bell right and left. The bell will sound as long as the circuit remains closed; but as soon as it is broken, the spring R will detach the armature, the hook of the lever *l* will press anew against the teeth of the wheel r_1, and all will be arrested. It is not the current, as we see, which moves the clapper of the bell, but it is the force of the spring; the only function of the current is to liberate the tooth of the wheel r_4, consequently nothing prevents our being in this way able to sound large bells, as has been done in England under particular circumstances.

The mechanism of the alarums has been modified in a thousand ways; sometimes the hammer is exterior and strikes only one blow; in Mr. Wheatstone's centrifugal bell two hammers are fixed at the extremities of a lever, mounted upon the axis of a wheel. Instead of a hook locking the wheel, it is sometimes a point which is dropped into a hole on the circumference of the wheel: frequently also the stop is a strong notched spring, which holds back the arm, that carries the hammer; when, in the movement of the armature, the spring is drawn back from the notch the arm falls and rings.

When the electro-magnet of the alarum is situated in the circuit of the multipliers of the needle of the telegraph, each current that passes, in order to produce a signal, would at the same time produce a ringing, which would be very disagreeable. This serious inconvenience is obviated by employing what is called a *short circuit*; namely, a shorter road is opened to the current to go to the galvanometer than the course through the electro-magnet of the bell. The short circuit is established by the single movement of the handle, that is at the right (*fig.* 372.). The two brass rods, that are

seen on the right of the figure 372., on the side of the bell-case, communicate respectively above with each end of the coil of the electro-magnet of the bell; they are continued in the interior of the telegraph and descend to the level of the handle; and at that level, a wire leads from one of them to the galvanometer coil of one of the needles, and from the other of them to the distant telegraph station. The brass substance of the handle communicates with the hinder rod; the other rod is metallically connected with the spring R, placed under the handle. A piece of ivory is let into the metal of the handle, upon which the spring R rubs. When the handle is vertical, the spring rests exactly upon the ivory; the handle and spring are insulated; the two rods communicate together only through the wires of the electro-magnet of the bell and the multiplier of the needle, the bell sounds, and the needle is deflected; but if the handle is turned horizontally, its metal substance communicates with the spring, the two rods are metallically united; the current is then able to go directly to the wire of the multiplier: as the new road is considerably shorter than the former, the current will follow it; and, although the circuit of the electro-magnet of the bell is also closed, but very little electricity will pass into it, too little for the bell to ring.

We shall not dwell upon the description of some less important parts of the needle telegraphs, the part played by which is easy of comprehension. We shall confine ourselves to a description given by Mr. Walker, from whom we have borrowed the descriptions that precede, of a small apparatus which it has been found advantageous to add to the principal apparatus, and which is called the *silent apparatus*. Its purpose is to prevent a despatch traversing the whole of the line, when it is being transmitted between one extreme station and an intermediate station. In fact, if we take, for example, the telegraph line that unites London with Dover, the wire, insulated along the whole line, communicates with the earth only at London and at Dover,—a communication, which takes the place of the return wire, all the apparatus of the required intermediate stations being in the circuit; it follows

from this that, if a despatch is being transmitted from London to Tonbridge, the current goes as far as Dover, where it finds communication with the earth. By means of a small disc and needle, which are seen at the bottom of figure 372., a rotatory motion may be imparted to a cylinder of box-wood, that is fixed normally to the centre of the disc; a brass plate communicating with the earth by means of a wire is let longitudinally into the wooden cylinder, against which press four springs, the two first of which are connected with the two wires from the London station, and the other two with the two wires from the Dover station. On turning the cylinder on one side or the other, the two London and the two Dover wires are made to communicate with the earth, the instrument being left in circuit with one or other station. These wires, in the ordinary state, are insulated from the earth at Tonbridge. This possible communication presents a double advantage; by reducing the distance traversed by the current, it premits of operating with more feeble piles, and by confining the signals within one portion of the wires—that comprised between the two stations which are put into communication—it leaves the other portion at the disposal of the stations that it includes. The name given to the apparatus arises from the circumstance that, when the moveable disc is so turned that the point of its needle is upon the word *silent*, the extremities of the galvanometers of the telegraphic apparatus, of the Tonbridge station, for example, are placed in immediate communication by means of a plate of metal; the result of which is that a despatch, which is not intended for this station, traverses it without affecting the instruments, in consequence of the shorter circuit, that the current finds, by means of the metallic communications, that are established between the respective extremities of the wire of each galvanometer.

The needle telegraph is generally employed in England; and in order to give a complete idea of the manner in which it acts, we are compelled to introduce here some details upon the mode of communication that is established between the various stations. The conductors employed for establishing

communication between the stations are iron wires of about $\frac{1}{6}$ of an inch in diameter (No. 8. gauge), generally covered with a layer of zinc, in order to prevent oxidation. These are supported by standards called *poles* from 15 to 20 feet high according to circumstances, 6 to 12 in. square at the base, and 4 to 6 in. square at the top; they are painted white, and are tarred at the lower part, where it enters into the ground; their mean distance is from 55 to $73\frac{1}{3}$ yards. Independently of the supporting poles, *winding* posts exist at regular distances; the mean distance of which is $\frac{1}{4}$ of a mile, intended as their name indicates, for straining the wires which, but for this, on account of their great length, would form a curve, that would bring them too near to the ground. It is essential that the wires should not be in immediate communication with the wood of the poles, which is a conductor, especially when it is moist, because the currents would be diverted; they would pass into the neighbouring wires or would penetrate into the ground, which would occasion great disturbances. In order to insulate them, supporters are employed of different forms of baked clay, or glazed porcelain*, which are fixed upon the wooden pole, and along which the wires are made to pass. Upon the early English lines a wooden arm was fixed against the supporting pole by iron bolts, which is separated from it by discs of earthenware, the arm itself carries four or more double cones of earthenware, retained by iron clips. The conducting wires traverse one of these cones, and are thus very well insulated; a double system of wires passes before and behind the pole, which is covered by a small wooden roof (*fig.* 377.).† In the figure, the supporting pole is on the left; the winding post which is on the right, is of larger substance. It is traversed in some cases by as many, in others, by half as many winders as there are wires; each winder carries on each side its *strainer*, composed of a drum and axis with wheel and ratchet; the ends of the winder are insulated from the post by earthenware

* We shall see that, in Germany and Switzerland, glass is generally employed (as it has often been in England) for forming the insulating supports.

† In order not to complicate the figure, we have represented only one of these systems.

discs, and the wires are attached to it on either side; in order to complete the circuit, a secondary wire is soldered to the

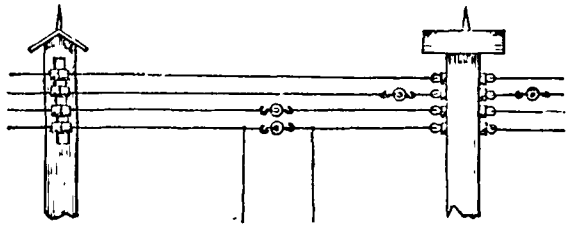

Fig. 377.

principal wire, on either side of the post.* The small piece that is seen on the right and left upon the second wire, and in the middle of the third and fourth, and what the English call a *shackle,* is formed of a porcelain ring, furnished with two hooks; one of the hooks is fixed to the centre of the pulley, the other is attached to it, by means of a looped ring, that passes round its circumference. They are therefore insulated from each other; it follows from this that the winding post is out of the circuit of the second wire,— a circuit, that is completed, as we have said, by a secondary conductor. With regard to the fourth wire, we see that there comes out from each of the two portions, separated by the insulating pulley, a conductor; and these two conductors enter into the telegraphic station in which the circuit is closed, either by the apparatus itself, or by a secondary conductor, if there is no despatch, either to receive or to transmit.

The system of insulation of conducting wires, that we have just been describing, presents more than one inconvenience; and therefore, endeavours have been made to substitute subterranean for aërial conductors; these are copper wires, covered with an insulating layer, generally made of gutta percha: further on, when we shall be occupied more in detail with the various modes of communication of telegraph stations

* At each winding post, only half the wires, in most cases, are interrupted; the other half passes the post, still being insulated from it by means of the double cones of earthenware, the axis of which they traverse. It follows from this arrangement, that since the poles are a quarter of a mile apart, each wire is half a mile in length.

with each other, and with the precautions necessary for preserving them against attacks of more kinds than one, which may damage them, we shall return to this system of conductors, which are not only much more expensive in erecting, but which in practice have presented inconveniences under some circumstances; so that in many instances they have been rejected, except in cases wherein it is impossible to do without them, as when the object is to pass through tunnels or to penetrate into towns.

If now we desire to form an idea of the manner, in which a telegraph system acts as a whole, we must take one particular telegraphic line, that of the South-Eastern Railway, from London to Dover, &c., placed under the direction of Mr. Walker, to whom we are indebted for the greater part of the preceding details, and who has himself introduced into the manipulation a great number of improvements, which his long experience and his profound knowledge of the subject have suggested to him. This line is complete and independent of all others; it extends from London to Strood near Rochester; from London to Dover, with branches to Reading, to St. Leonard's and Hastings, to Maidstone, to Rye and Hastings, and to Deal, Ramsgate, and Margate. The total length of telegraph which it embraces is over 300 miles. The stations are distributed into groups, so that there shall not be more than six or seven in a group. The most important group is that from London to Dover; it requires two wires, independently of the return by the earth, which is brought about by means of a wire called *the earth wire*, which coming from the apparatus, is put into communication with the earth by the intervention of a plate buried in the earth, or by objects, that are naturally buried in it, such as gas pipes, &c.; the wires pass into certain of the most important intermediate stations, Tonbridge, Ashford and Folkstone, which are provided with instruments, independently of those which are at the two extreme stations. At each of these stations, the wires are interrupted by means of insulating pulleys (*shackles*), described above (*fig.* 377.); and conducting wires, leading from the principal

wire on each side of the pulley, abut upon the instruments, as we have explained. Thus two wires are sufficient to establish telegraphic communication between London, Tonbridge, Ashford, Folkstone, and Dover; each of these five stations is furnished with the double needle apparatus; at each intermediate station, as well as at the two extreme stations, is found an earth wire; we have seen its employment, which enables us to shorten the path of the current, when the despatch is not needed to traverse the whole of the line. One of the two wires is placed in communication with the alarum, in order that one may be warned when a message is about to be transmitted; but when once the warning is taken, the alarum is placed in short circuit, the wire only communicating effectually with one of the two multipliers of the apparatus, the other wire being already in communication with the second multiplier. We have already seen that we can prevent the current passing into the multipliers, when we are satisfied that the despatch is not intended for the station, by offering to it a shorter circuit. Two wires are necessary for the two-needle telegraph; one alone is sufficient for the one-needle telegraph not including the return by the earth. It is not necessary as we have explained, to have a special wire for the alarum; however, with the one-needle telegraph, which requires only one wire, it is the custom to devote the second to the alarum.

Independently of the two wires, that serve the five stations, that we have mentioned, there are other pairs of wires for stations of an inferior order, and which form different groups. These wires are not respectively in one length along the whole line; they are interrupted at the extreme stations of the groups, to which they belong. However, it follows from their establishment, in connection with other subdivisions, &c., including wires solely for train-signals, that twenty-seven wires reach the London station by the line on which we are engaged. This might cause it to be thought that these twenty-seven wires are indispensable for the telegraphic work; now, as we have seen, between London and Dover only two are necessary; one

alone would even have sufficed. But if there had been but two wires to serve, for instance, all the stations which form part of this line, the direct communications between London and Dover would have been perpetually interrupted; or rather it might have been the communications with the intermediate stations that would have suffered. On this account it is that, when once the poles are established, it has been found more advantageous to increase the number of the wires, which leads to a very moderate increase of expense.

At the different junction-stations are placed a kind of turning platforms, which are a sort of commutators, intended for changing at pleasure the communications, so as to give the power, in case of necessity, of employing the wire of the principal line for stations on branch lines; as, by means of switches, the direction of trains is changed upon railways. Thus, at the central station at Tonbridge, Mr. Walker has in the office a turn-plate, which is able to cause his London telegraph apparatus to communicate with Hastings; and there are similar arrangements elsewhere. Mr. Walker's turn-plate is a wooden cylinder or drum, into which are inlaid plates of brass, and against which steel springs press, which communicate with the extremities of the conducting wires.

The piles employed on the line from London to Dover are piles of a wooden trough, with plates of zinc and copper, of about sixteen square inches of surface; the compartments of the troughs are separated by partitions of slate, and the cells are filled with a silicious sand, moistened with water, acidulated by means of sulphuric acid, and in which the plates of the pairs plunge. Figure 373. contains the representation of one of these piles. In practice it is preferable to increase the number of pairs, and to employ only a feeble acid solution, rather than to have a stronger one with a smaller number of pairs. Moreover, the number of pairs is varied with the distance by which the stations are separated. Thus, for the groups of stations between which the distances are only ten or fifteen miles, twenty-four pairs are employed; from Tonbridge to either extremity of the line, which comprises a distance of forty or fifty miles, forty-eight pairs are re-

quired; from London to Dover sixty are required. We may add that the zincs are amalgamated; they are able to serve six or eight months without having need of being amalgamated afresh; and even ten or twelve, if care is taken to wash the sand well from time to time with a current of water. Mr. Walker also has many piles in which he has substituted graphite for copper, and employs no sand. All the telegraphs and signal apparatus, 232 in number, on the South-eastern line, which is over 300 miles in length, with 1350 miles of wire and 135 stations, are served by means of 5319 pairs; and the Electric Telegraph Company's system in Great Britain, which is 5398 miles in length, with 28,627 miles of wire, and 423 stations, requires 70,000 cells.

In terminating that which concerns the double needle telegraph, let us now recall to mind the manner in which it is employed. The following is, first, the complete vocabulary: —

A. Two movements toward the left of the left needle.

B. Three movements toward the left of the left needle.

C and 1. Two movements of the left needle, the first to the right, the second to the left.

D and 2. Two movements of the left needle; the first to the left, the second to the right.

E and 3. A single movement of the left needle toward the right.

F. Two movements to the right of the left needle.

G. Three movements of the left needle toward the right.

H and 4. A movement toward the left of the right needle.

I. Two movements toward the left of the right needle.

J. is omitted, and substituted by G.

K. Three movements toward the left of the right needle.

L and 5. Two movements of the right needle; the first to the right, the second to the left.

M and 6. Two movements of the right needle; the first to the left, the second to the right.

N and 7. A single movement toward the right of the right needle.

O. Two movements toward the right of the right needle.

P. Three movements toward the right of the right needle.

Q is omitted; K is substituted for it.

R and 8. A parallel movement toward the left of both needles. The lower end is read in this and the following signals.

S. Two parallel movements toward the left of both needles.

T. Three parallel movements toward the left of both needles.

U and 9. Two parallel movements of both needles; the first to the right, the second to the left.

V and 0. Two parallel movements of both needles; the first to the left, the second to the right.

W. A parallel movement of both needles toward the right.

X. Two parallel movements of both needles toward the right.

Y. Three parallel movements of both needles toward the right.

Z is omitted, unless made with one beat more than Y; or S is substituted.

The sign +, called *stop* by the English, is the final point, by which the person, who sends the despatch, announces that the word is finished; it is indicated by the movement of the left needle towards the left. This sign serves also for him who receives the despatch to indicate that he does not understand; when he understands, he shows the letter E; two E's, or rather two movements of the left needle, are employed for saying *yes*.

The words *wait, go on*, engraven upon the instrument, are useful signals. If London addresses Dover, when Dover is occupied and is unable to lend attention to the correspondence that London is about to open, Dover directs the lower end of the needles to the letter R, and says by this act, *wait*. When he has become at liberty again, and ready to receive the message, he directs his needles to W, which means *go on*.

It is especially important for the two stations that are opening a correspondence to understand each other well before commencing. It is necessary that the one, who receives should know well who is sending to him; and that the one who sends a message should know clearly if it is the station with which he desires to correspond, that really receives it. Above the six large letters +, E, H, N, R, W, are engraved the names of the stations of the group; and these stations will henceforth be always designated by these letters. In the apparatus (*fig.* 372.) R, is London, E, Tonbridge,

H, Ashford, N, Folkestone, W, Dover. If, now, London desire to correspond with Tonbridge, he directs his needle to E for a few moments, each movement causes the Tonbridge bell to ring, should it be in circuit, which, as we have seen, would be situated on the same wire as the left needle; the attention of the clerk is roused; he puts his alarum out of circuit, and transmits to London the same signal, which corresponds to actually saying, *All right, I am at my post;* London is then sure of being understood at Tonbridge. He then directs the needles upon the letter R, which indicates London; and Tonbridge, in his turn, knows that it is London that is speaking to him; and by repeating this same signal R, he says that he has received it. London then goes on with Tonbridge; the correspondence commences; and Tonbridge, after each letter says E, *understand,* or the stop +, *not understand.* When the despatch is completed, London makes two deviations of the left needle towards the left; the clerk at Tonbridge repeats them, if he has nothing to add, and proceeds to the transmission of the despatch to its ulterior destination.

Two telegraph clerks are able to modify their vocabulary in such a manner, that the intermediate stations that see their signals, are unable to decipher them. They can agree, for example, that the right directions shall be read to the left, and reciprocally, for one of the needles or for both; 2nd, that the left needle shall become a second right needle, or the right needle, a second left one; 3rd, that the right needle shall become the left needle, and the left the right, &c. &c.

The figures are written under certain letters; and the sign H, followed by the +, indicates, that a figure is about to be indicated, and not the corresponding letter. In order to avoid all errors, the correspondent immediately repeats the same H +, indicating by this, that he expects a figure and not a letter. The letter W, interposed among the figures, serves to separate compound figures, or decimal fractions. Thus, H, E, W, N, means 43*l.* 7*s.*, or 43 ft. 7 in., or 43h. 7m., &c. Special signals indicate periods, paragraphs,

words underlined, or other important circumstances; the clerks have invented a signal for laughing, and for expressing their astonishment, &c. &c. The English clerks are so well skilled that they are able to send the most difficult despatches, even when no letter or figure or signal may be engraved upon the dial of their apparatus.

As may be supposed, the double needle telegraph may easily be arranged so that it shall act as a single needle telegraph only, which is very valuable in many cases; as for example, when one of the two wires, necessary to the double needle telegraph, has become deranged or broken; or when the two wires, by the effect of a violent storm or an accident, have come into contact, so as to constitute one only. Moreover, the single needle telegraph, although its manipulation requires a little more time, is able to render great service; it is not unfrequently employed for the notices to be given on railways between the various stations.

The double needle telegraph is perhaps the most perfect of all in theory; and, although it requires the employment of two wires, it merits the preference in the majority of cases, both on account of its simplicity, the action upon which it depends being a direct action, which does not require any intermediate mechanism, and also on account of its infallibility, which is due to the same cause, since it is less susceptible than any other of becoming deranged, and giving rise to errors. The facility with which the handles lend themselves to the movements to be executed, and the rapidity which results from it in the transmission of despatches, are equally remarkable. Mr. Walker, as the result of his long experience, has observed that, in ordinary cases, from fifteen to twenty words per minute, are easily transmitted; that very frequently, when all is in order, and the insulation is good, twenty-five or more are transmitted. These considerations explain why the double needle telegraph is generally adopted in Great Britain; why it is retained, notwithstanding the evident superiority in many respects, as we shall see,

that is presented by Morse's telegraph; they will likewise serve in our justification for the extended developments that we have devoted to it.

There remains another needle telegraph contrived by Mr. Bain, which was set up in 1846 upon the line from Edinburgh to Glasgow. This telegraph is a single needle one; however, the number of movements necessary for forming a signal never exceeds four; this is only one more than in the double needle telegraph, and the same number as in Cooke and Wheatstone's single needle; it has the same advantage as the latter in requiring only one wire. This telegraph, like the preceding one, depends upon the action that is exercised upon the magnet by the current that traverses the wire of a bobbin; but the arrangement of the different pieces of the apparatus is very different; the two permanent magnets of a semi-circular form are connected together by means of a brass rod in the diameter of their circle, upon which is fixed, perpendicularly to this diameter, the indicating needle, which comes from its centre, through which also passes the axis of rotation. The two semi-circular magnets have their poles of the same name near to each other; there exists between them an interval of not more than a sixth of an inch; two bobbins are so placed that, in the state of inaction, the two neighbouring poles of the magnets are likewise in the interior of the same bobbin. It follows from this that, as soon as a current penetrates into the wire of the bobbin, one of the poles is driven from the interior of the bobbin, whilst the other penetrates into it; which produces, according to the direction of the current, a movement of the indicating needle, either to the left or to the right. The same effect takes place upon the other two poles of the two semi-circular magnets, which likewise penetrate into the interior of a second bobbin. It is now easy to comprehend that, by means of a commutator, we are able to produce movements of the indicating needle as numerous as we desire, and which rapidly succeed each other either to the right or to the left, and the direction of which deviations is carefully made to coincide with that of the motion

that is imparted by the hand to the arm with which the handle is furnished, by which the commutator is made to move.

Endeavours have been made to employ the induction currents, produced by permanent magnets, instead of the current of a pile, in order to make the needle telegraphs act. There have resulted from this some very notable modifications in the construction of the apparatus; but, as this same mode of production of electricity has been applied to other telegraphic systems, we shall include under the same examination the study of the telegraphs in which magneto-electricity is the motive force.

Dial Telegraphs.

Under this name are designated the telegraphs in which a needle traversing a dial by a succession of elementary impulses, in the same direction or in contrary directions, is able to stop during a very short instant, upon any point, and to show consequently all the letters of the alphabet or any signs. Sometimes it is the dial that is movable, and that stops an instant, when the letter or the sign, upon which we desire to direct attention, is in a certain determined position. The greatest advantage of the dial telegraphs is that each sign is shown directly to the clerk, and that its perception is the result of a single instant of attention; he who transmits the signal has also to impart only one simple rotatory motion, more or less prolonged, in order to bring the indicating needle upon the sign to be shown at the distance, or the movable dial to the place where the sign is to be found. The dial telegraphs are founded upon a principle analogous to that of the alarum of which we have spoken above; there is always an electro-magnet, which is magnetised by the current, that we have under our control, which, acting upon an armature, or as it is called, *a contact* of soft iron, produces by means of this piece of soft iron, a movement in a system of wheels more or less complicated — a movement which is imparted directly by the piece in question, or which results from a mechanism, foreign to the electro-magnet, the

action of which is arrested and liberated, according to the position of the piece, as takes place in the alarum. The inconvenience of some of the dial telegraphs is that, in general, each signal in them being dependent upon those which go before it, errors are liable to accumulate: their mechanism, besides, is necessarily always more or less complicated, which renders them more susceptible of being deranged, and consequently very difficult to regulate and maintain regulated. It is also to Wheatstone that we are indebted for the first idea of the dial telegraph; he has himself constructed a very great number of them, endeavouring to perfect them. He is not the only one; for, both in England, as well as in Germany and France, a multitude of them, more or less ingenious, and more or less perfect, have been devised. Being constrained to keep within bounds, we shall confine ourselves to speaking of those dial telegraphs the superiority of which has been made known by practice; we shall not even dilate at very great length upon that which concerns them, seeing that the employment even of the best of them is not very general, comparatively with that of the needle telegraph of which we have already spoken, and with that of the Morse telegraph, with which we shall be engaged in the sequel.

In order to make the mechanism of the dial telegraph fairly comprehensible, we shall begin by describing the most simple of all, which is rather intended for the demonstration of the principle than for being employed in practice. In this telegraph, as in all the others, we must distinguish the *manipulator* and the *receiver*. The needle of the receiver (*fig.* 378.) is mounted upon a wheel *a*, which possesses twenty-six teeth, corresponding to the twenty-five letters of the alphabet, written upon the dial, and to the sign +, called *final*, which serves as the starting-point. These teeth are cut in a plane inclined in respect to the radius, and in respect to two pins, *b* and *d*, of the pallet *b c d*, which receives a backward and forward movement from the right to the left, and from the left to the right; when the pallet goes to the left, the pin *b* strikes upon the middle of the inclined plane of the tooth, which it meets, and by the pressure causes the

wheel to advance half a tooth; when it returns, the pin *b* is liberated, and the pin *d*, in its turn, causes the wheel by the

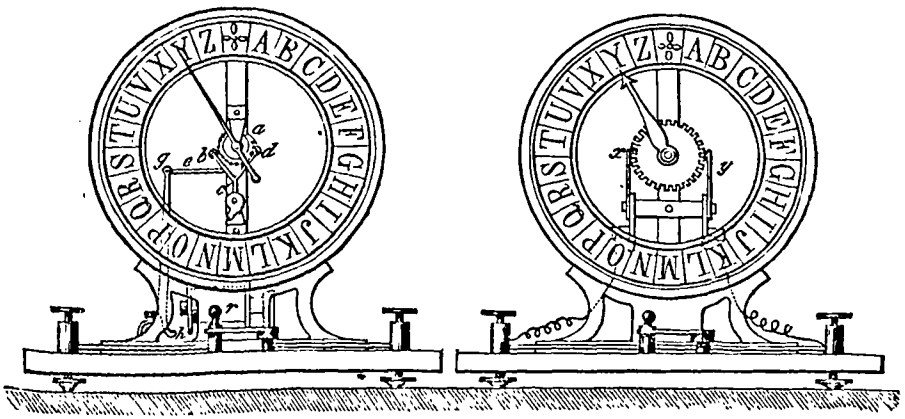

Fig. 378. *Fig.* 378. *bis.*

same mechanism to advance half a tooth in the same direction. These motions are imparted to the pallet by the extremity *g* of the lever *g h*, which is attracted to the right by the electro-magnet *r*, when the current passes in its wire, and which a spring brings back to the left, as soon as the current ceases to circulate. Suppose the needle stopped on the *final*, it will be brought upon the letter A by closing and interrupting the circuit once; upon the letter B, still setting out from the *final*, by repeating the same operation twice, and so on for all the other letters. Let us now see how the manipulator (*fig.* 378. *bis*) produces this effect; it carries a dial precisely similar to the preceding; only its needle, which is stronger, is moved by the hand, and in its motion draws on the wheel, upon which it is mounted; the latter possesses twenty-six teeth; two springs are placed to the right and left, one of them, *y*, performs the office of the catch in the ratchet wheel by preventing the wheel from turning backwards, and is always found in contact with it; the other, *x*, touches it by a projecting terminal only, when one tooth passes before it; two connecting wires, each of which is attached to one of the extremities of the wire of the electro-magnet of the receiver, are attached, the former to the positive pole of the

battery, the latter to the spring y, whilst the spring x communicates with the negative pole. It follows from this arrangement, that each time that a tooth passes before the spring x, the circuit is established, and that it is interrupted when this same spring is situated in the interval that exists between two teeth. Thus, when the needle of the manipulator is made to pass from one letter to the following, there is produced successively a closing, then an interruption of the circuit; which causes also the needle of the receiver to pass precisely in the same manner from one letter to the following. Consequently, if the two needles are in accordance (and it is for this purpose that the *final* is employed, upon which the needles of both apparatus must always be stopped, when they are not acting), they will pass on together to all the letters, indicating them simultaneously; and in order to transmit a word, we have merely to stop the needle of the manipulator for an instant, at each of the letters of which it is composed. Each station must have a battery, a manipulator, and a receiver; the clerk who receives the despatch, keeps his battery and his manipulator at rest out of the circuit; there is nothing else to do than to follow with his eyes the needle of his receiver, in order to read what it indicates. When it is his turn to transmit a despatch, he takes his receiver out of the circuit by means of a commutator, and at the same time introduces into it his battery and his transmitter; he causes the alarum of the station to which he addresses himself, to ring, his correspondent performs a reverse operation, and the communication is established. The apparatus that we have just been describing, excellent for demonstration, is inferior to others of the same kind in respect to velocity and safety in the transmission of despatches; the derangements to which it is liable, arise from the circumstance that the pallet of the scapement of the receiver is sometimes liable to allow a tooth instead of a half-tooth to pass, on account of the velocity of the impulse, and from the fact that the hand of the person that causes the needle of the transmitter to turn, has nothing to guide, and especially to stop it exactly where it ought to be done; the least hesitation

it may suffer, either onward or backward, may produce some want of agreement between the needles.

Mr. Wheatstone's first apparatus, although less perfect than those which he has constructed more recently, does not, however, present the inconveniences that we have just been pointing out. In this apparatus (*fig.* 379.), the armature A,

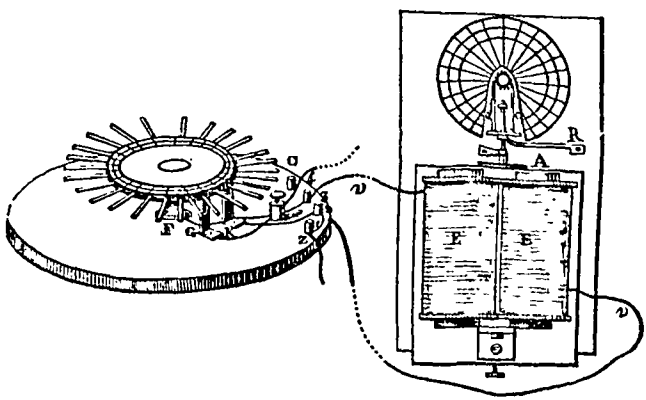

Fig. 379.

is attracted by the electro-magnet E E, as soon as the current passes; and immediately it ceases, this same armature, being driven on by the reaction of a spring, returns to its first position. On closing, therefore, and opening the circuit alternately, the armature is made to advance or to return. This alternate motion in opposite directions is transformed into a circular motion in a single direction, by means of the two rods or arms of the lever *c* and *d*, the arm *d* drawing the tooth when the attraction is exercised, and *c* pushing it when the attraction gives place to repulsion; it follows from this that the wheel *b*, and consequently the disc of paper or the dial fixed upon it, advances one step each time that the attraction or repulsion ceases. Upon the circumference of the dial are written the letters of the alphabet or other signs, in a number double of the number of the teeth of the scape-wheel; that is to say, in the present case twenty-four (the twenty-four letters of the alphabet). The instrument is enclosed in a box, which is not represented in

the figure; a plate of brass, which also is not seen, placed before the dial, carries a small opening which enables one to see at the same time only one of the signs that are traced upon the dial. Each of the signs may be brought at pleasure before the opening, by establishing and breaking the circuit a sufficient number of times. Such is the receiver or *indicator*; with regard to the transmitter or manipulator, it is formed of a brass circle, moving freely around a foot, F, also of brass; the circumference of the circle has twelve notches filled with pieces of ivory or hard wood, in such a manner that it presents equal intervals of conducting and non-conducting substance; a spring, G, presses against this circumference, whilst another spring, K, rests against an ivory ring, furnished at its circumference with a piece of brass in metallic contact with the circle. Four binding screws are connected by wires in the following manner: 1 with 2; 2 with the spring K; 3 with the support F; and 4 with the spring G. The two poles of the pile are respectively connected with the screws 1 and 4; and the two wires that are to put the receivers in the circuit, with the screws 2 and 3. The upper surface of the circle possesses characters corresponding to those of the dial; and twenty-four little pins, intended for facilitating the rotatory motion produced by the finger. There is a stop which prevents the finger's being able to draw on the circle beyond the desired point. When the apparatus is not in action, the sign + must be found opposite this stop; the spring G presses against one of the non-conducting divisions of the circumference of the circle, the spring K being always resting against the piece of brass placed upon the ivory ring. In this arrangement, the battery is not in the circuit which, if required, permits of the conducting wires that are thus found free being employed for a communication coming from the station where the receiver is, to that where the manipulator is, by means of a similar apparatus, but arranged in a reverse manner. Now if we turn the circle with the finger, the spring G passes alternately over the conducting and non-conducting divisions; and the circuit is thus in turn closed and broken, which

causes the dial of the receiver to move onward as many teeth as there have been interruptions in the transmitter. If, therefore, all has been properly adjusted, in order to make a certain letter appear upon the dial of the receiver, we have merely to apply the finger to the pin corresponding to the same letter upon the transmitter, and to bring it as far as in front of the stop; this movement will bring about the number of the interruptions of circuit necessary for making the wheel, and consequently the dial that is fixed to it, move on the given number of teeth, in order to obtain the desired result.

Mr. Wheatstone has devised many methods of transforming the alternate motion of the armature into an intermittent circular motion of the dial. The direct mode that we have just been describing, which is the most simple, requires too strong a current to be employed when the distance to be traversed by the despatch is considerable. Thus, in the improved apparatus, intended for long lines, Mr. Wheatstone has connected the signal-dial with a clock movement set in action by a spring on a weight, which, when there is no preventing cause, communicates to the wheel to which the dial is fixed, a rapid rotation. But a mechanism analogous to a scape-wheel and pallets, does not allow of the wheel advancing more than the distance of a half-tooth, each time that the armature is attracted by the electro-magnet, or repelled by means of the spring, to which it is connected, when the magnetisation ceases. The instrument thus becomes much more sensitive, and is able to act with a much more feeble current. In fact we can see that it would require much more force to give motion directly to the dial than to liberate a simple scape-wheel. It is likewise by the addition of a clock-movement that Wheatstone has succeeded, as we have already seen in respect to the alarum, and of which we shall see other examples further on, in obtaining a multitude of mechanical effects.

The dial telegraph, as we have already said, has received a very great number of modifications, one of the most happy of which is that which has been introduced to it by M. Bréguet,

who has rendered the instrument much more certain and much more easy in using. He has also introduced a clock-movement, which tends to cause the wheel to move onward, upon which is placed the needle that is intended to traverse the dial of the receiver; the electro-magnet ceases here also to be the motor; it is nothing more than an interrupter permitting the clock-movement to cause a half-tooth of the wheel to pass, and stopping it just at the moment when it has passed, permitting it to cause the following half-tooth to pass, in order again to stop it, and so on. That which especially distinguishes M. Bréguet's telegraph, is the particular scapement that he has placed in dependence upon the electro-magnet, in order that the latter may discharge its functions well; namely, in order that it may very correctly allow one half-tooth to escape at each return vibration. The scapement acts by means of two small pallets, mounted upon an axis, which is only an axis of oscillation, and which are arranged at such a distance and in such a manner that the tooth of the wheel is unable to pass without encountering them; an encounter which, by means of the play of the electro-magnet, only takes place at the fitting moment. M. Bréguet's manipulator is likewise arranged in an ingenious manner, which contributes also, on its part, to remedy several inconveniences of the dial telegraph. We shall return to these mechanisms when engaged with the telegraph of conventional signs, likewise constructed by M. Bréguet.

But one of the most ingenious among the telegraphs of this species, is without controversy that of M. Froment. The improvements devised by M. Froment, are to be found especially in the transmitters or manipulators. Figure 380. represents this apparatus complete. A, B, is the manipulator, in which are distinguished the twenty-eight keys of the finger-board which form its exterior part, and which are under the hand of the person who sends the despatch, exactly as the keys of the piano are under the hand of the pianist. The letters and the different signs are engraved upon them in the same number and in the same order as upon the dial of the receiver

C D, which is seen in elevation, but which can be as far off as we please from the manipulator. This latter is furnished

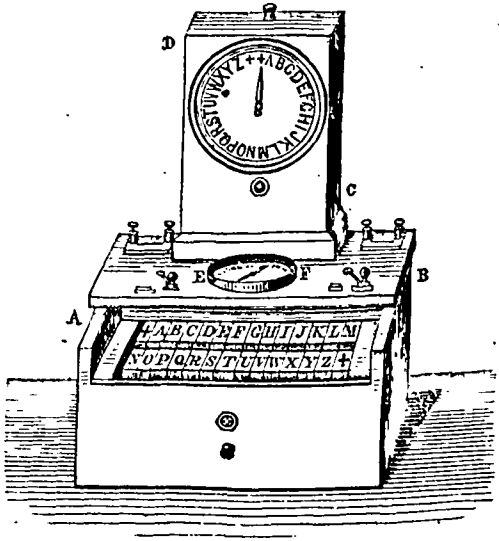

Fig. 380.

with its call-bell, the hammer of which is set in motion by a special electro-magnet very ingeniously arranged, which is set into action on pressing a key of the finger-board of the manipulator.

The most important piece of the manipulator is a steel arbor, straight and very stiff, which goes from one extremity to the other of the case (*fig.* 381.); upon this arbor are set

Fig. 381.

as many arms as there are keys, that is to say, twenty-eight; these arms, all equal and perpendicular, divide into twenty-eight equal parts, the length of the arbor, comprised between the first and the last key; they likewise divide its circum-

ference equally into twenty-eight equal parts; thus forming the complete revolution of a helix. Moreover each key carries in the middle of its thickness, and in the proper point of its length a stop-pin, under which the corresponding arm of the steel arbor passes freely when the key is in its natural position, but against which it strikes and stops, when the key is lowered and pressed by the finger. The steel arbor itself is set into rotation by a clock-movement, and is furnished with an interrupting wheel, as in ordinary transmitters, which opens and closes the circuit for each turn a number of times, which depends upon the number of signs to be transmitted;* the needle of the receiver goes on or stops according as the cylinder turns or remains at rest, when at least the circuit is established. At the extremity of the arbor is found a ratchet wheel, which, arrested by a horizontal lever, prevents the arbor in the ordinary state from turning. But, on lowering a key, the horizontal lever is made to move, which thus liberates the ratchet wheel; the clock-movement then causes the arbor to turn until it is again stopped, when the peg corresponding to the key arrives before the latter. Immediately the key is raised, the horizontal lever again catches the ratchet wheel. Thus each key causes the clock-movement to go on as soon as it is pressed; and the latter is stopped when the arm of the rotating arbor, which corresponds to the depressed key, comes and encounters it; but as the needle of the receiver travels synchronously with the arbor, by means of the interrupting wheel, it follows from this that this needle, which stops at the same time as the arbor, then indicates a sign corresponding to that which is marked upon the key that has been depressed.

The action of M. Froment's telegraph is at the same time very rapid and very accurate. The last wheel of the clock-movement turns with a great velocity; it makes, for example, one, two, and even three rotations per second, and it consequently imparts this same velocity to the steel arbor

* As the finger-board has 28 keys corresponding to the 28 signs, the wheel has upon its circumference 14 teeth and 14 empty spaces.

which it carries. This great velocity does not interfere with the regularity of the action of the apparatus. Thus the interruption-wheel has on its circumference fourteen teeth and fourteen vacant spaces, since the finger-board has twenty-eight keys, and there are consequently twenty-eight signs to transmit; the contact of the spring and a tooth produces the closing of the circuit, whilst the passage of a vacant space before the projection of the spring produces the rupture. We understand, then, that the needle of the receiver being upon the mark +, it is necessary, in order that the finger-board shall be in accordance, that the arm of the steel arbor which corresponds with the key marked +, shall be precisely under its stop-pin; the arms, corresponding to the letters A, B, C, &c., are thus found respectively at distances from their stops of $\frac{1}{28}$, $\frac{2}{28}$, $\frac{3}{28}$, &c., of the circumference; then, if any key is pressed, we bring about precisely the rotation necessary for the needle of the receiver to come and stop upon the letter corresponding to this key, and the same agreement is indefinitely sustained whatever be the velocity of the rotation of the arbor. The regularity of the action is such that the hand may be passed from one end of the finger-board to the other in any manner, without order or any attention, by pressing even several keys at once, without the receiver and the finger-board having lost their agreement; on placing the finger upon a key, we see the needle of the receiver mark the corresponding letter, as if the apparatus had just been regulated.

We cannot, as we have already said, dwell upon all the very numerous modifications which the dial telegraph has undergone; such as the employment of clock-movements, moving synchronously at the two stations, and which are stopped by the aid of electro-magnetic actions at the same instant; such as the substitution of pieces of magnetised steel for the ordinary armatures of soft iron, which enables us to do without the spring employed for restoring the armature to its former position. In fact in this case, the electro-magnets act upon the armature already magnetised

of itself, by repulsion, as well as by attraction, according to the direction of the current; the sensibility of the apparatus is thus increased, and it is independent of the variable intensity of the current, which requires that the spring be regulated, when the armatures are of soft iron, for each particular intensity. M. Gloësener, who has employed magnetised armatures in the construction of the different systems of telegraphs, has found in it the advantage that is likewise presented, as we shall see, by the employment of magneto-electric machines instead of piles, that of destroying more rapidly, by the production of induced currents, the magnetisation of electro-magnets, which remains sometimes for some instants after the current has ceased to pass. But, notwithstanding these various advantages we think that, if magnetized armatures have not been generally adopted, it is because their magnetisation must alter very rapidly under the intermittent action of electro-magnets.

All alphabetic telegraphs, both those which we have just been describing, as well as those which resemble them, may be characterised in a general manner, by saying that they have necessarily a manipulator, which is moved by the hand of the person who sends the despatch, and that, consequently, he who receives the despatch, is obliged to be still and to remain passive, until his correspondent gives him the liberty of speaking in his turn. With regard to the differences that exist between the various apparatus, they depend only upon the mechanism that serves to transform the backward and forward movement into a rotatory motion, or upon the arrangement of the dial or upon the form of the interrupter, or finally upon the number of the divisions both conducting and non-conducting of which it is composed. It is not the same with the telegraph devised by Mr. Siemens, which differs totally from others in that it maintains to the operator who is receiving the despatch, even while he is receiving and writing it, his direct and immediate action over the operator who is sending it to him, and this without having recourse to a second wire, without disturbing the agreement of the dials and of the apparatus, and without introducing the smallest disturb-

ance into the series of signs, the transmission of which is commenced.

In order to realise this advantage, Mr. Siemens altogether suppresses the interrupter; and he arranges his dial apparatus in order that it may act exactly in the same manner, whether it may be necessary to send a despatch or to receive it. In order to explain clearly the ingenious mechanism by means of which this result is obtained, we will borrow the description of it from the very remarkable report that M. Pouillet made to the Académie des Sciences in 1850, upon the dial telegraph of Mr. Siemens.

The armature of the electro-magnet carries a lever of about four inches in length, which performs two very different actions.

By the first, at each double vibration (going and returning), it causes one tooth of the wheel to pass, upon the axis of which is mounted the indicating needle of the dial; and consequently it carries this needle from one letter to the letter that follows.

By the second action, it breaks the circuit and arrests the current, from which it has itself received motion; but it does not arrest it until the moment when it is itself arrested by a stop in its *onward* excursion, that is to say, when the armature, attracted by the electro-magnet, has arrived as near to the poles as it ought to go; then, the circuit being broken, the armature ceases to be attracted, and finding itself immediately drawn back by its spring, the lever accomplishes its *return*. Scarcely does it touch this other limit of its excursion than it completes the circuit afresh, re-establishes the current, and instantly is found to be carried on anew by the armature, in order to accomplish its second onward movement, which, from the same cause, is followed by a second return. These isochronous vibrations will thus be accomplished indefinitely, as long as the pile furnishes a current of the same intensity; they would then become slower, when the pile is weakened; and finally, they would cease, after a longer or a shorter time, when the action of the current should become too feeble for the attractive force of

the electro-magnet to be able to overcome the inertia of the armature and the tension of the spring, which retains it at a distance from the poles.*

Two similar apparatus introduced into the circuit, one at Berlin, the other at Paris, worked together, and with perfect synchronism, saving the velocity of the electricity, which may here be neglected; and, if they were in agreement at the first instant — that is to say, if the needles corresponded in the same sign — they would make thousands of revolutions, and would work for days or for entire years, being found always agreeing; that is to say, always at the same instant opposite the same signs.

No operator is necessary; the pile takes charge of everything.

However, hitherto the indicating needle of the dial would have merely a regular and jerking movement, analogous to that of the seconds' hand of a time-piece; it would, however, be much more rapid, for the indicating needle would be able to make an entire revolution per second, requiring only a thirtieth of a second to pass from one sign of the dial to the following sign, which supposes in the lever of the armature thirty double vibrations per second. It is true that Mr. Siemens tries his apparatus with a velocity only one half of this; that is to say, of one revolution in two seconds, or one double vibration of the lever of the armature in one-fifteenth of a second. This does not, however, mean to say that his telegraph is able to make fifteen signs per second, or 900 per minute; for the eye could scarcely follow the needle: besides, with this regular and uniformly jerking motion, it points out all signs equally, and makes as a last result the same thing as if it had not indicated any one, since the observer who follows it is unable to distinguish anything, to make out anything in its movements: it acts very nearly as some one who

* This system, which consists of employing the magnetising action of the current itself, in order to interrupt or to establish it, had already been put into practice both by myself in the construction of the apparatus, that I have termed *electro-chemical condenser*, and which I have described in the First Volume of this Treatise, as well as by other philosophers, and particularly by M. Froment, in several of his ingenious apparatus.

might be reciting the alphabet several times consecutively with a perfectly regular and monotonous voice, without making any letter in particular to be perceived; unquestionably it would be altogether impossible to make out what he might desire to say.

It is, therefore, necessary to add something to the mechanism of which we have just been speaking; it is necessary to arrest the needle in its course, not for a long time, but for half a second, a third of a second, or, perhaps, a quarter of a second, according to the accuracy of the movements of the person who is sending the despatch, and the more or less prompt perception of the person who is receiving it, by which the needle points out, selects, or, if you please, pronounces in some sort the letters, to which the operator must exclusively direct his attention. In order to obtain this result, Mr. Siemens adjusts circularly around his dial as many keys as it carries signs, and upon each key is repeated, in a very conspicuous character, the sign to which it corresponds. On placing the finger upon a key, a small vertical end of the tenth or twentieth of an inch in diameter is depressed, which then stops the passage to a horizontal lever, parallel to the needle and mounted upon its axis. It is exactly as if the needle itself were stopped; but the mechanism is concealed beneath the dial, in order not to confuse its appearance, and not to fatigue the attention of the operator. It is not sufficient that the needle be stopped very faithfully opposite to the sign that it should indicate; it is further important that the motor-lever, connected with the armature, the vibration of which is also arrested by the same obstacle, shall be then situated toward the middle of its return; that is to say, towards the middle of the excursion that it makes under the influence of the spring, that brings it back. We understand, in fact, that at this instant, the circuit being broken for a certain time, and the effects of the current having ceased, there is less chance that the armature should contract a magnetic polarity, capable of disturbing the regular action of the apparatus. These conditions are very skilfully fulfilled by Mr. Siemens.

The person, therefore, who sends the despatch, has only one single operation to perform; to place his finger successively upon all the keys that correspond to the series of signs that he desires to transmit. He depresses a key, and the indicating needle of his apparatus, carried on by the regular motion by which it is actuated, does not yet suffer anything; it continues its course till the moment when it arrives at the sign whose key is depressed; there it stops. The needle of the other station, moved by the same force and subject to synchronism, cannot however stop mathematically at the same instant; for the lever which causes it to move, brought back also by its spring, accomplishes its return with force, since it does not encounter, like its homologue of the first station, a material obstacle which stops it; it therefore accomplishes its return, and takes the position in which, as far as it is concerned, it completes the circuit and re-establishes the current. However, what it then does cannot have its full effect at the very instant, since its homologue of the first station is then retained in a point where it breaks the circuit. Thus is it that the operator who sends the despatch, placing his finger upon a key for a certain fraction of a second, brings about a moment of similar stopping in the needle of the second station; but we must particularly remark that the two needles cannot stop at the same instant; the second does not stop until after a time, which is equivalent to nearly the quarter of the duration of a complete vibration. This circumstance is important by the influence that it exercises over the number of signs that may be transmitted in a given time.

When the person who is sending the despatch, raises his finger, that he had placed upon the first key, in order to carry it on to the second and make the second sign, the following phenomena are accomplished. The lever of his apparatus, obeying the action of the spring which draws it, is finally free to accomplish its return, and in fact it does accomplish it. Then, the circuit being everywhere closed, the current is re-established; the armatures of the two stations are simultaneously attracted, and the needles recover their

concordant progress until the moment when that of the first station marks the second sign; the needle of the second station repeats it in its turn, and the same phenomena are reproduced until the end of the despatch. If everything goes on well, the operator of the second station has nothing else to do than to follow with attention the movements of his indicating needle, to write or to dictate the signs that it points out to him. If he has a doubt, he places his finger upon a key; then the needle of the first station stops at that signal, and the person who is sending the despatch, is thus warned that his correspondent wishes to speak; the conversation goes on, explanations are exchanged, and the original operation soon resumes its course.

The apparatus of which we have just given a summary idea, is sufficient of itself; it has no need of any auxiliary, and it presents no other chances of error than those which may arise from the observer, who might have been deceived either in reading the movements of the needle or in writing the signs, after having read them. In order to avoid even the possibility of these errors, Mr. Siemens joins, when required, to his apparatus a printing press, which operates likewise by an electro-magnetic action, the origin of which is in a local pile, a pile whose circuit is closed in order to set the printing apparatus into action by the current which causes the telegraph itself to act. The intervention of the local pile is necessary from the need there is of having, in order to make the electro-magnetic printing apparatus act, more energetic electric current than that which is required by the telegraph itself, which current besides is already reduced by the course which it has traversed from one station to the other. We shall not enter into further details upon the very complicated mechanism of this apparatus; as, moreover, is that of all the different printing telegraphs that have been devised before and after that of Mr. Siemens; for the exposition of the principles upon which these telegraphs depend, we shall refer to the following section, which will be devoted to registering telegraphs.

Mr. Siemens's telegraph requires, in order to its acting

well, a perfection of execution, which has been realised by Mr. Halske, a skilful mechanician of Berlin, but which in general can be attained only with difficulty. This circumstance, added to the complication, and consequently to the high cost of the apparatus, has rendered the employment of it not very general; but it in no degree diminishes its theoretical value, which is further increased by the new and interesting considerations upon the electric telegraph which the inventor has included in his description of it; considerations to which we shall have occasion to return further on.

In the category of dial telegraphs we should also evidently place the signal instrument constructed by M. Bréguet for the French administration. It is intended for reproducing the same signs as those which were given by the ancient aërial telegraphs; the administration of the French telegraphic lines having found various advantages in this modification, introduced into the ordinary dial telegraphs, first, that of having a staff accustomed to those signs, the use of which has been established for half a century, and the vocabularies of which had been for a long time agreed upon; then to obtain a more rapid transmission of despatches, since, on making use of the ancient signs, not only letters but words are transmitted; finally, to be more easily assured by it of the secrecy of the despatches. This last advantage is not very real; since, as we have already said, nothing is more easy than to obtain it with any telegraph, by means of a previous agreement, analogous to those which are made for ordinary correspondences, when they are put into cipher. The first two advantages, although well founded, are not however sufficiently great to compensate for the inconveniences that result from the complication of the apparatus, from the greater difficulty of its manipulation, as well as from the necessity of two telegraphic wires, and a very energetic electric current, in order to make it act. Thus we think that these telegraphs will end by being totally abandoned, as they already begin partially to be, in France, which is the only country where they have been employed. This it is which induces us to confine ourselves

to giving a very summary description of them, notwithstanding the interest, in a mechanical point of view, that may be excited from the very skilful and ingenious manner with which M. Bréguet has succeeded in solving the problem, the solution of which had been demanded of him by the French administration.

The telegraphic system in question consists of a double dial telegraph, which permits of two needles being made to move; these needles are each able to assume eight different positions in respect to a horizontal line — positions which are consequently 45° distant from each other. By combining each of the eight positions of one of the indicating needles with the eight positions of the other, sixty-four signs are thus obtained. The two needles are each moved by a clock-movement, and carry upon their axis a scape-wheel furnished with four teeth, which are sufficient for obtaining the eight given positions.* The escapement is made by means of a pallet moved by an electro-magnet. This is represented in *fig.* 382., in which for each indicator, *a* and

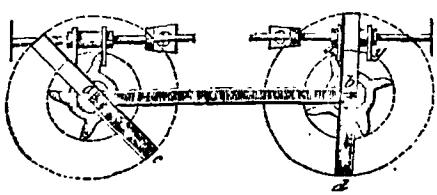

Fig. 382.

b, are seen the two pallets *x* and *y*, a portion of the oscillating arbor, by which they are carried, and the four-toothed wheel, which allows just a half-tooth or $\frac{1}{8}$ of the circumference to pass, when the oscillation of the lever liberates one of the pallets, in order to take hold of the other. Only, as we have said, the system is double; as there are two indicators, which must be moved in a perfectly distinct and independent manner, each has its clock-movement, its scapement, its electro-magnet, and its distinct current. From this

* This system is similar to that employed by M. Bréguet for his dial telegraph, of which we have spoken above.

it is easy to comprehend the working of the apparatus, which requires simply a clock-movement sufficiently powerful, and at the same time very accurate — conditions which are with difficulty reconcilable, but which have been so, thanks to the skilfulness of M. Bréguet.

Let us now pass on to the manipulator, which is composed of two independent parts similar to that of the figure 383.; each of these is in connection with one of the sides of the receiver by a special wire, which arrangement, as we have already said, requires the employment of two wires. The two manipulators are identical; so that it is sufficient to describe one of them.

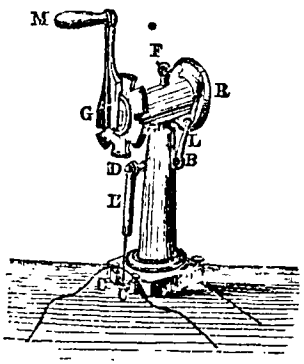

Fig. 383.

G is a fixed disc divided into eight equal parts by notches, in which a rod, fixed to the movable handle M, may be caught; R is a wheel, likewise fixed, upon one side of which a quadrangular collar with rounded angles is hollowed out, in which moves a roller carried by the upper part of the lever L; B, D, is the axis of motion of the two levers L and L′; L is the lever that carries at its extremity the roller which enters into the wheel R, that has the collar; L′ is the lever that carries in its lower part a spring-piece, oscillating between the contacts C and C′; C and C′ are two metallic contacts let into a piece of ivory, upon which the lever L′ is made to rest; C communicates with the pole of the pile; and C′, with the receiver by a conducting wire; the line-wire is fixed to the bottom of the column. On causing the handle to move in the same direction, as many times as it shall have passed before the notches of the disc G, so many times will the lever L′ have produced an interruption of the current by the effect of the levers L and L′.

The receiver and manipulator complete, are represented in *fig.* 384.; we see only the external appearance of the receiver, the form of the box, in which are the clock-move-

ments, and the scapement, that we have described (*fig.* 382.). We likewise see the face that is turned toward the operator, presenting above, on the right and on the left, two little dials,

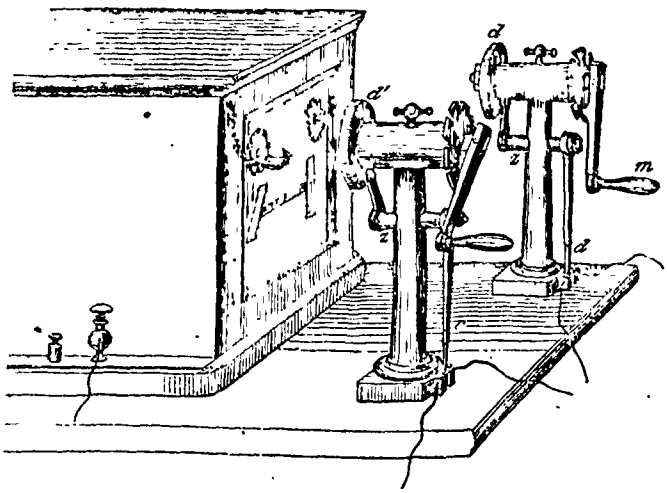

Fig. 384.

which are employed for regulating the tension of the spring of each armature; then, a little lower, the fixed horizontal regulator, and the two indicators, each of which is mounted upon the axis of the four-toothed wheel (*fig.* 382.), in order to move with it. The two manipulators are likewise represented in *fig.* 384. The handle *m*, which is hinged, is taken in one hand; it is withdrawn a little from the circle *a*, and is turned, in order to carry it into one of the eight notches, where it is stopped by a pin that it carries. The indicator, which it causes to move on, stops also in the same position. What we have just said of the handle *m*, is applicable to the other, which on its part acts in the same manner upon the indicator that is under its influence. Thus both hands are at work; and after some time of practice they acquire a marvellous skilfulness in this kind of operation, in which it is necessary that they should lose all habit of symmetrical motions. The simultaneous working of both handles, to the left and to the right, causes, therefore, the two needles of the receiver to move to the left and to the

right, as well at the station of him who is sending the despatch, as at the station of him who is receiving it; only the latter is obliged to place and to retain his manipulator out of circuit during the whole of the time that he is receiving the signals from his correspondent.

We have already said that the dial telegraphs required in general the employment of tolerably energetic currents; also they are generally made most commonly to act with Bunsen's piles. In France, in particular, these pairs are employed with the telegraphic apparatus, having the old signals. It is even necessary to employ piles composed of many of these pairs; in some cases in order to insure working, as many as thirty are employed, which involves a very heavy expense. With regard to the conductors, they are in France aërial wires, supported by wooden posts and insulated by means of porcelain supports. In Prussia, where the telegraph of Mr. Siemens has been employed, subterranean wires, insulated by gutta-percha, have for a long time been employed. Mr. Siemens has given a detailed description of this mode of communication, which, moreover, appears to have been abandoned, notwithstanding the precautions that had been taken, in order to render it as perfect as possible, and the means devised for discovering the points where a communication with the ground had taken place, when, perchance, it had been established as the result of some solution of continuity in the insulating layer.

Registering Telegraphs.

Registering telegraphs are those which leave a permanent trace of the despatch transmitted by registering it, as their name indicates, so that it may be preserved and checked. We can recognise the great advantage that results from them for the telegraphic service, both by rendering errors much more rare, as well as by permitting of their being traced to their origin, when they do slip in.

Printing telegraphs, of which we have already spoken in reference to Siemens's telegraph, belong to the category of registering telegraphs; but they are neither the most simple,

nor, consequently, the most in use. Their object is to furnish the whole of the despatch printed in ordinary characters. They are in general composed of four different mechanisms: 1st, Of a composing mechanism, by means of which a wheel carrying the characters of the alphabet, engraven in relief, presents before a mark that one of the characters which is intended; 2nd, Of a system for inking the characters; 3rd, Of a printing mechanism, that presses the band of paper upon which the despatch is to be printed, against the type or character placed before the mark; 4th, Of a governor of the band of paper necessary for guiding it well, and making it advance after each impression of a letter, sufficiently far for the impressions not to be superposed. The great difficulty of the problem was to obtain the acting of these various mechanical organs under the influence of a same current; and it is principally by the means employed for overcoming this difficulty, that the different systems which have been proposed, are distinguished from each other. We have already indicated that in Mr. Siemens's printing telegraph, it is by means of a powerful local battery, the circuit of which is closed by the current that sets the dial telegraph in action, that the mechanism intended for producing the impressions is set in action. But a long time previously Wheatstone had been the first to devise writing the despatches, by having recourse to a distinct apparatus, formed of twenty-four bands or springs carrying characters in relief, and hammers, which, by striking individually each band, printed the letter upon the paper, with several copies. Mr. Brett had introduced in his telegraph an improvement which consists of printing the despatch, by means of a second indicating dial, that is passed against the paper, charged with lamp-black. But more recently, he had himself devised a printing telegraph, in which the function of the printing mechanism is brought about by the aid of a centrifugal force regulator, under the influence of a resting time sufficiently maintained for the transmission of the letter that is desired to be printed. In Mr. Brett's telegraph this function is accomplished by the intervention of an hydraulic apparatus, the

ascending movements of which are easily brought about, and the movements of the conduit of which are slowly accomplished. In a system, recently invented by M. Theiler, the telegraphic mechanism is in synchronous movement with that of the transmitter; so that we have merely to stop the latter in front of such or such a letter in order that the telegraphic mechanism shall be immediately stopped, and shall present this letter to the printing mechanism. But the latter is found to be put into action under the same electric influence which has brought about the stopping of the other telegraphic mechanism. In a system devised by M. Du Moncel, the telegraphic mechanism moves on under the influence of the current sent in a certain direction; and the printing mechanism performs its function under the influence of the same current sent in the contrary direction. Did we desire to make a complete enumeration, there would be yet many other trials of the same kind to cite; but, all these apparatus are so expensive, so slow in the transmission of despatches, so delicate in their working, and, consequently, so liable to become deranged, that however perfect they may be,* they will probably never become practical; and that for registering telegraphs, the telegraphs with simple signals will in fact always be preferred, which do not necessitate a numerous staff, and to which a very abbreviated stenographic language may be made to apply. It is therefore of these latter that we are about to occupy ourselves, the more so as, independently of the property which they possess of registering the despatch, they present so many other advantages that their employment tends to become, as we have said, always more general.

It was in 1837 that Morse made known to the public the registering telegraph, which has justly retained his name, and of which it plainly appears that he had conceived the idea as far back as 1832. Its principle is very simple. This

* Of all the different systems of printing telegraphs, the one certainly that acts with most rapidity is that of M. Theiler; it possesses besides the advantage of being very simple in working for the operator. It might, therefore, not be impossible that it may be employed practically in certain special cases; for example, when the question is to furnish a means for blind persons to write themselves, without having the need to dictate.

telegraph requires but a single circuit; consequently but one single insulated wire, and the return by the earth. At the extremity of the circuit, where the despatch is to be received, is an electro-magnet, the wire of which communicates by one of its extremities with the ground, and by the other with the insulated wire, that establishes communication between the two stations. The armature of the electro-magnet is fixed at the end of a small lever, the other end of which carries a pen or a pencil. Under the point of the pen or pencil travels on, with a uniform motion, a band of paper, which is moved by means of mechanism. Now, at the extremity of the circuit, whence the despatch sets out, is a pile, one of the poles of which communicates with the ground, whilst the other pole may be put at pleasure into communication with the insulated wire, by which the two stations are connected. If the circuit is closed, the armature of the electro-magnet is attracted; and this attraction causes the point of the pen or pencil to touch the paper, and to trace upon it a line, the length of which depends upon the time during which the circuit has remained closed. If the latter is closed and opened rapidly, there are produced upon the paper simple dots, the number of which depends upon the number of times that the circuit is interrupted and established. The blank space by which the points and the lines are separated, is greater in proportion as the circuit remains open for a longer time. We therefore see that we may at pleasure, by acting at one of the stations, trace upon the paper, that is unrolled at the other, a succession of points or lines, separated by blank intervals, which may be combined in very various manners, in order to give rise to signs corresponding to the different letters of the alphabet, and to the various figures of arithmetic. Mr. Morse has done this; and his system of signs has been generally adopted with a single modification, the fitness of which has been made manifest by practice; it is, instead of employing two lines, one longer than the other, besides the point, to have only two signs; namely, one line always of the same length and one point. We shall see further on how, by means of this point and

this line, all signs of which we have need in the transmission of despatches, may be represented. We have supposed, in that which precedes, that the transmission of the despatch took place in one direction only; it follows, as a matter of course, that in order to its taking place in both, a double system of apparatus is required.

Without dwelling upon the various successive modifications that Morse's system has undergone, I will describe it immediately as it is now generally applied, especially in Germany and Switzerland, where, thanks to the improvements successively introduced by Mr. Steinheil and by M. Hipp, it attains a high degree of precision and rapidity in the transmission of despatches. The registering or writing apparatus (*fig.* 385.) depends upon the combination

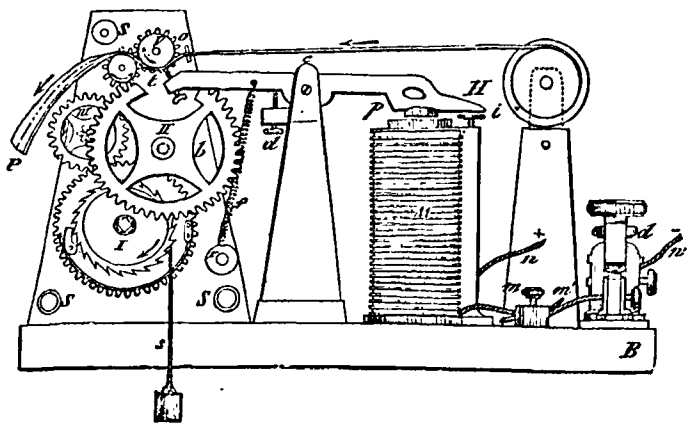

Fig. 385.

of two essentially different apparatus; one consists of a lever, H, which, when it is lowered, presses upon a sheet of paper, P, with a point, *t*, with which it is furnished. This lever is depressed by means of the electro-magnet H, which attracts the armature *p*, fixed to the levers; every time that the current passes in the wire of the electro-magnet, the armature in fact draws the lever to which it is fixed, and thus produces the pressure of the point against the paper. A screw, *i*, serves to limit the play of the armature, and a helical spring, *f*, attached to the lever, compels it, by its elasticity, to separate itself from

the electro-magnet, when the current ceases to act, which causes the point m to longer to press. The other part of the apparatus is intended to cause a long band of paper, P, to pass under the point with a uniform velocity, which paper is rolled upon a cylinder, and is for this purpose pressed between two brass cylinders, with a roughened surface O and V. Two springs retain the upper cylinder pressed against the lower cylinder, which is set in motion by a clock-movement, by means of a weight, *s*, for which an ordinary spring has now been substituted with advantage. The paper is drawn on between the two cylinders by the motion of the lower cylinder, and thus passes under the point. With regard to this point, after having tried successively a pen and a pencil, the difficulty of furnishing ink to the pen and of cutting the pencil caused them to be rejected, in order to substitute for them a point of very hard steel; in order that this point or rather stylus may leave its impress upon the paper, a groove, which corresponds to the stylus, has been sunk upon the upper cylinder V; it follows from this that when the lever is attracted by the electro-magnet, the stylus, reaching the paper, presses it against the bottom of the groove, which produces a distinct mark. If the stylus presses upon the paper only for a very short time, it marks a dot only; if it acts for a longer time, it makes a dash; it is able therefore to mark dots and dashes, which, as we have said, is sufficient for forming a complete alphabet.

Before describing the transmitting apparatus represented by *fig.* 385. in profile in *d*, we must make known an essential apparatus in Morse's telegraphic system; it is that which has been termed *the relay*, an apparatus, moreover, which is made use of in many other applications of the same kind. The object of the relay is, when the current of a battery transmitted to a great distance by a telegraphic wire, is too feeble to cause the receiving apparatus to act in a direct manner, to employ this current to cause the more powerful current of a local battery to act upon the apparatus; a function which requires but very little force in the current. Now the receiver in Morse's telegraph requires, in order to

its acting, a very energetic current, and at least the employment of very powerful batteries, which would be very expensive, and frequently very troublesome; it cannot be made to act by a current transmitted from one station to the other. Recourse is, therefore, had to the relay, which consists (*fig.* 386.) of an electro-magnet E E, the wire of which is placed

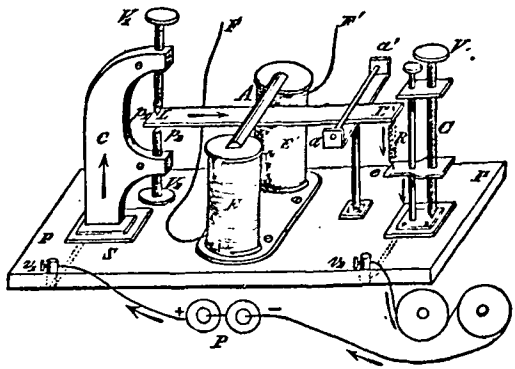

Fig. 386.

by the extremities F and F′ in communication with the telegraphic line; so that this electro-magnet operates under the action of the current transmitted from one station to the other. The soft iron armature A is attached to a lever L L, movable around the axis $a\,a'$; the extremity L is moved between two screws p_1 and p_2, one of which p_1 is terminated by an ivory point, and the other, p_2, entirely metallic, communicates by means of the metal column C, and the conductors S v, with the pole of a local battery P; the other pole of this battery communicates by the intervention of the wire of the electro-magnet of the registering apparatus and of the spring R, with the metal lever L L′. When the telegraphic circuit, or F F′, is opened, the electro-magnet does not act, the extremity L of the lever rests against the ivory point p, by the effect of the spring R; but if the circuit is closed at the departing station, the armature A of the relay is attracted, L touches the metal point p_2, and the circuit of the local battery P being closed, the receiving apparatus of the arrival station is able to act. The screw V C′ serves to stretch more or less the spring R, in order to regulate the play of the

relay, according to the intensity of the current.* It is now evident that if the local battery has sufficient force to make the receiver of Morse's telegraph act, every time that there may be a short or a prolonged contact in the transmitter of the starting station, there will be a short or a prolonged contact at p_2, and in like manner in the receivers; thus the signals may be produced by the intervention of the relay as well as directly, only the relay enables the local battery to act in order to form them.

It now remains for us to make known the manipulator, designated also in this case by the name of *lever-key*. It is composed (*fig.* 385. *d*, and *fig.* 387.) of a small metal hammer,

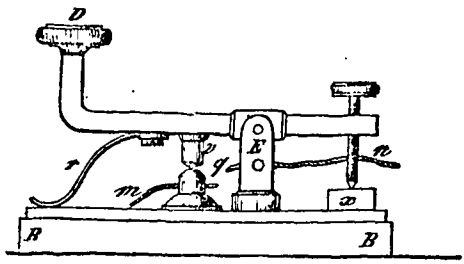

Fig. 387.

v, raised by a spring *r*; and which communicates with one of the wires *n* of the circuit; below the hammer is a small metal anvil, *q*, communicating with the other end, *m*, of the circuit-wire. We are thus able by resting with the finger in D upon the spring, to close or to break the circuit at pleasure; if the contact between the hammer and the anvil is produced for a very short time only, the current will pass in the circuit only during this instant; by maintaining it on the contrary for a longer time, the current will be able to pass during the whole time in the telegraphic wire. It is manifest that the lever-key is a very simple apparatus; however, an arrangement of a little more complicated character has been given to it, with

* The spring is intended to draw back the arms of the lever into its former position, when the electro-magnet ceases to act; but it is essential, in order that a great number of movements may be produced in a given time, that this spring should act rapidly. M. Hipp has proposed for this purpose, instead of one spring, to place two opposed springs, the tension of which is modified, but in such a manner that one, which brings back the lever in its first position, is allowed to prevail; a combination which, when the apparatus is in action, gives rise to a more rapid drawing back, than when there is but one spring.

a view of making it fulfil, both the office of the manipulator, and that of a means of communication between the station whence a despatch is coming, and the station at which it is itself situated. It is constructed, therefore, in such a manner that it satisfies the following conditions:—1st. When a despatch is transmitted, to leave open the circuit of the local battery, and that of the *principal** battery of the departure station. 2nd. In the state of rest, to leave the circuit of the telegraphic line closed, in order that the current of the line, coming from the neighbouring station, may circulate. 3rd. To allow at the same time that this current may circulate around the electro-magnet of the relay, so that at the moment when it circulates, the circuit of the local battery may be immediately closed. 4th. Finally, to cease to be in communication with the relay at the moment when the circuit of the principal battery of the station is closed, in order that the current of this battery may go directly to the apparatus of the other station, without being compelled to traverse the wire of the electro-magnet of the relay which is at the departure station. The following apparatus (*fig.* 388.)

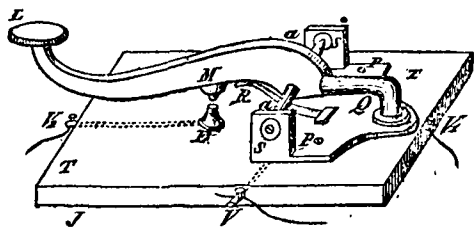

Fig. 388.

fulfils the desired conditions very well. Upon a small wooden table, T T, is a brass plate, P P, with two vertical metal supports, S S, in which are resting the extremities, *a a*, of the axis of a lever with two branches, L L, always in metallic contact with the plate P P. Upon one of the extensions of the lever is placed a hammer, M, below which is a small metal anvil, E, from which it is kept apart in the state of rest by a spring R. The other extension of the lever,

* We designate under this name, in opposition to the local battery, the battery intended for furnishing the current, transmitted through the telegraph wire from one station to the other, which is called *line current.*

bent at right angles in Q, is then in intimate contact with a small metallic cylinder, surrounded by an insulating ivory cylinder, and communicating with the binding screw V_1. The anvil communicates with another binding screw, V_2, and the plate P P with the third screw, V. It is to this last screw that the line wire or the earth wire is attached, so that in the state of rest the principal current, entering by the plate, arrives by Q at the screw V_1, which communicates with the relay of the station. But if the lever is pressed upon so as to make the hammer M and the anvil E touch, the line wire or the earth wire is put into communication with the screw V_2, which communicates with one of the poles of the principal pile, the other pole of which leads to the earth wire or to the line wire, and it then acts upon the relay and consequently upon the telegraphic apparatus of the other station.

It is easy for us now to represent the manner, in which communication is made between two stations. It is necessary that there should be at each, 1st. a principal battery and a local battery; 2nd. a writing apparatus; 3rd. a relay; 4th. a lever-key. The lever-key at each of the stations communicates in a permanent manner with the ground, by means of a conductor, which leads from the screw V, in contact with the metal plate P P; it communicates by the screw V_1 with one of the extremities of the wire of the electro-magnet of the relay, the other extremity of which abuts upon a metal piece, to which likewise the line wire abuts; this same piece is in communication with one of the poles of the principal battery, the other pole of which communicates with the screw V_2 of the lever-key. It follows from this arrangement that, if the lever-key of the second station is lowered, the principal current of this station causes the relay of the former to act, since its circuit is complete.*

* The current, indeed, coming from one of the poles of the principal battery, arrives at the metal piece of the relay, where it finds the end of the line-wire, traverses this wire, then arrives at the metallic piece of the relay of the former station, traverses the wire of the electro-magnet of this relay, arrives at the screw V of the lever-key, thence goes into the ground, whence returning to the second station, it penetrates by the earth-wire into the lever-key of this station; which being depressed leads it to the screw V_2, which is in communication with the other pole of the pile.

This circuit is on the other hand broken as soon as we press upon the lever-key of the former station; but then we place in the circuit of the telegraph wire the principal battery of this station, which is about to act upon the relay of the second, supposing that its lever-key is in a state of rest, as it must naturally be when it is not acting; now, the action is never going on at both stations at the same time.

To the three apparatus, that we have just described, the registering apparatus, the relay, and the lever-key, Mr. Steinheil has added one, which he has named *transferrer*, which is intended to transmit a despatch between two stations, that do not immediately follow each other, through intermediate stations. It is indispensable for this to introduce into the circuit the principal batteries of each station; for the current of one of these batteries alone would not be able to overcome the resistance that is presented to it by the whole of the conductors, by which two very distant stations are connected with each other. We can conceive that this operation may be easily accomplished by means of lever-keys, furnished with an electro-magnet, which when they are traversed by the current of the line, produce in the lever to which they belong, a motion that closes the circuit of the principal battery, exactly as this takes place when it is pressed with the finger; thus the despatch may be transferred in one direction or the other; this is why the name of transferrer has been given to the apparatus. In the state of rest, it is necessary that the transferrers of each station shall connect the ground with the extremities of the telegraphic wire, comprised between two consecutive stations; but when we desire that the despatch shall traverse the intermediate stations, in order to arrive directly at an extreme station, it is necessary that the keys should be depressed, so as to break communication with the ground, and to introduce the principal battery into each of the partial lines, that unite together the intermediate stations. The key of the transferrer may be lowered in one direction or in the other, according as the despatch travels in a certain direction or in the converse direction.

But it is a more simple plan to unite the transmitter to

Morse's writing apparatus, as Mr. Steinheil has already done; which can be easily accomplished by means of a slight addition to this apparatus. Indeed, it is merely necessary to add to the end of the lever of the writing apparatus, opposed to that where the stylus is situated, a small piece, which comes into contact with another beneath it at the moment, when the lever is set in motion by the attraction of the electro-magnet. This contact, by an arrangement, which is easy of comprehension, closes the circuit of the principal battery of the station, where the apparatus is, so as to transmit the despatch to the following station and so on. The despatch is thus transmitted from one extreme station to another extreme through all the intermediate stations, leaving its trace in each of them. It is useful, however, that it may also be able to pass without leaving its trace. This double object is accomplished by means of a commutator, which the persons on duty so arrange that, after a first signal having come from the first station, which indicates the point whither the despatch is destined, the current of the local battery is able to place the principal battery in the telegraphic circuit, without causing the writing apparatus to act, except at the station to which the despatch is to arrive.

Mr. Steinheil, who has so ably contributed to the perfecting of the electric telegraph, had found it convenient to join to the principal batteries of each of the stations a considerable resistance, the extent of which might be changed without interrupting the current. He had accomplished this by means of a rheostat, consisting of a very fine brass wire; by so selecting this wire that a length of 40 feet, presents very nearly the same resistance as 16,000 feet, or one league of the conductor, he succeeds, by brass wire of from 400 to 600 ft. in length, in producing resistances equal to those of the conductors, comprised between two consecutive stations or of that which we call partial lines. We shall not describe the details of this rheostat so arranged that, in a very brief instant, one is able to introduce into the circuit resistances equal to one, two, three, and up to eleven leagues of the line wire; a second rheostat added to the former, allows of intro-

ducing likewise very promptly resistances equivalent to $\frac{1}{10}$ of those of the former, that is to say to $\frac{1}{10}$, $\frac{2}{10}$, &c., of a league of the line wire. The necessity of this introduction of a variable resistance into the circuit is due to the importance of having a current of constant force, in order to act upon the relay; seeing that the apparatus, when once adjusted by the tension of the spring, ceases to act well, if the current becomes more or less intense than that under the influence of which it has been adjusted. Now, the current that sets the apparatus in motion is variable; for its intensity depends upon the state of the battery, which, even in the most constant batteries may vary; and especially on the insulation of the line wire, which changes with the degree of humidity of the air and of the supports. Every day, therefore, it is necessary to vary the additional resistance, arising from the introduction of the rheostat into the circuit, so as to have, as much as possible, a current always of the same intensity, which is determined by means of a compass, surrounded with a galvanometric wire, which forms part of the principal circuit, and with which each station is provided.

The adjustment of the force of the current regulates the action of the apparatus; and it furthermore enables us to know the condition of the whole of the line; for the losses of current are the more powerful, and consequently the insulation of the line wire the more imperfect, in proportion as it is necessary to increase the deviation of the compass at the departure station, by diminishing its resistance, in order to obtain at the other station the deviation, that corresponds to the normal current, under the action of which the apparatus ought to work. Notwithstanding the incontestable advantages of the rheostat, we shall however see, in a moment, that experience has shown that it might be dispensed with without inconvenience; and that it was more simple and convenient to adjust the apparatus every day, according to the variable intensity of the current, by putting more or less tension upon the springs of the relays.

Before going further and pointing out by certain practical details the manner of using Morse's telegraph, it is time to make known the nature of the signs or alphabet, which it has

been arranged to employ. As we have already said, the signs are two in number; a dot and a dash; and it is by numbering them two and two, three and three, and four and four, that they have succeeded in obtaining in all thirty different indications, corresponding to the letters of the alphabet and to certain diphthongs. The following is the Table of these combinations, placed opposite to the letters which they represent, as well as of the ciphers, for which five signs are employed: —

Letters.	Signs.	Ciphers and Punctuation.	Signs.
a	· —	1	· — — — —
ä	· — · —	2	· · — — —
b	— · · ·	3	· · · — —
c	— · — ·	4	· · · · —
d	— · ·	5	· · · · ·
e	·	6	— · · · ·
f	· · — ·	7	— — · · ·
g	— — ·	8	— — — · ·
h	· · · ·	9	— — — — ·
i	· ·	0	— — — — —
j	· — — —	.	· · · · · ·
k	— · —	;	— · — · — ·
l	· — · ·	,	· — · — · —
m	— —	:	— — — · · ·
n	— ·	?	· · — — · ·
o	— — —	!	— — · · — —
ö	— — — ·	«	— · · · · —
p	· — — ·	Apostrophe	· — — — — ·
q	— — · —	Mark of Division	— — — — — —
r	· — ·		
s	· · ·		
t	—		
u	· · —		
ü	· · — —		
v	· · · —		
w	· — —		
x	— · · —		
y	— · — —		
z	— — · ·		
ch	— — — —		

We have seen that the stylus of the writing apparatus is in contact with the paper, as long as the lever-key is held down; the length of the marks, traced by the stylus, is proportional to the time of the depression of the lever-key, and the interval between two marks depends upon the duration of the pauses between two successive depressions. But the successive production of dots and dashes by the depression of the key, requires a measured rhythmic movement; without which it is impossible to trace in a regular manner the successive signs; for time is the measure of the length of each sign; and it is consequently necessary to employ the natural measure that we possess for time, which is rhythm. In order fairly to comprehend the action of the lever-key, it is therefore necessary to exercise oneself to depress it in tune. With this view we strike upon a table with the tip of the fore-finger of the right hand in two different manners: 1st. By drawing back the finger with rapidity so that it rests upon the table for an instant only, and by raising it only half an inch. 2nd. By leaving the finger resting upon the table for the time that separates two blows of the first kind, and by raising it for an equal time. Each beat of the first kind is measured by the syllable *di*, which is pronounced, while making the beat; with regard to the beats of the second kind, they are measured by pronouncing the syllables *do-o*. The beats, that are made while pronouncing the *di*, would produce dots, and those which are made while pronouncing *do-o* would give dashes, if the finger had been rested on the lever-key that sets Morse's writing apparatus into action; but it is better first to learn the use of the telegraph without apparatus, and by merely practising oneself to strike upon a table, in the manner that we have pointed out. We must then practise ourselves in producing a dash and two dots, then two dots and a dash, and so on, always pronouncing during these movements of the finger the syllables *di* and *do-o*, each syllable requiring to be pronounced at an equal distance from the following. We see that intervals of equal times elapse between two dots, from one dot to the following dash, from the commencement of

the dash to the end, and from the end of the dash to the first following sign. Each dot requires only a single interval of time, whilst the dash requires two. In the formation of the groups, that result from the combination of dots with dashes for the representation of different signs, regard has been had to the number of intervals of time, so as to have the fewest possible.

After a little practice, one easily succeeds in writing distinctly twelve or fourteen words in a minute and in reading double that number in the same time; only it is essential that the lever-key shall have but a very limited play in order that the *do-o* or beats of the lever-key, when it is lowered and raised, shall follow each other at equal intervals. We succeed very quickly in distinguishing by the ear the dashes from the dots, the lever-key making a noise similar to *tri tri tri* for the dots, and to *do-o* for the dashes; we succeed also in distinguishing them, both by the action of the relay, as well as by the action of the lever of the writing apparatus. The persons in charge are therefore able to comprehend the correspondence sent simply by the action of the apparatus and to write it so to speak under its dictation, at the same time as it is registering it, which in many cases is very advantageous.

We shall not pause to describe the distribution of stations and the arrangement of the lines, points to which we shall return further on, and which are independent of the telegraphic process employed. We shall simply confine ourselves to remarking that, in Morse's system, in which it is very important that the relays act under the influence of a current of an intensity as uniform as possible, care is taken to divide the *principal* lines, as much as can possibly be done, into *partial* lines of such a length, that the current shall have in them sensibly the same intensity from one end to the other; these partial lines unite the principal stations, which are all furnished with apparatus complete for receiving and transmitting despatches; so that when a despatch is to go beyond, the principal battery is put into the line circuit by means of the transferrer, in order to act upon the following relay.

Now, if the principal batteries are similar at each principal station, as well also as the resistances of the partial lines, we can conceive all the relays to operate under the action of a current of very nearly the same intensity. However, notwithstanding this precaution, variable circumstances, such as the moisture of the air, the imperfect insulation of the wires, which is the result of this, both by the air itself, as well as by the posts, the accidental contact of a wire with any external object, such as the leaves of a tree, may weaken the current between two intermediate stations. It is also necessary, as we have already said, to adjust the apparatus every day.

Among the operations, that serve for regulating the apparatus, we shall not dwell upon those which consist in preparing the battery, in adjusting each apparatus, in order to be assured of its working well, that the springs are of proper tension, that the points of contact in the relay and the lever-key always present a very clean surface, that the band of paper in the writing apparatus travels well, that the stylus is quite in its place, &c. &c. We shall confine ourselves to dwelling upon the operation, that consists in regulating the force of the current. We have already said that it is, by means of the permanent introduction of a great resistance, by the effect of a rheostat, into the circuit of the principal battery, that Mr. Steinheil obtained each day the current of the desired strength. This method has been abandoned in several telegraphic lines, where they have confined themselves to causing the number of pairs to vary, being guided approximately according to acquired experience. This is what M. Hipp is particularly doing at the present time in Switzerland; where the current is regulated on the morning of each day for the whole of the day, by withdrawing from or adding certain pairs to the pile, without the necessity of introducing any very sensible derangement into the apparatus.

Moreover, M. Hipp has introduced several other modifications, the advantage of which he has been led to perceive from long experience, in the telegraphic system as it has been

established in Switzerland by Mr. Steinheil. Of twenty-three transferrers, which were formerly placed in the telegraphic network of Switzerland, M. Hipp has left but eleven; and has found that great amelioration in the service has resulted from it. As the result of very interesting researches upon the functions of the transferrers, and on the relation, that exists between the force of the electricity and the rapidity of the movement of the armatures, he has been led to this considerable reduction in the number of these apparatus. But his numerous experiments upon this subject have especially demonstrated to him the excessive importance of always having currents of similar force; and it is in order to obtain this result that he has proposed the following system, which works with great success in Switzerland; and which might equally be applied to other countries with certain modifications, dependent on the extent and the distribution of the telegraphic network.

Every morning*, before the service commences, at a minute fixed upon beforehand, the central office of Berne calls all the offices of the principal stations and gives a constant current, which traverses these offices in the following order: *Zofinque, Zurich, Saint-Gall, Coire, Bellinzone, Lucerne, Zurich* (2nd time), *Bâle, Chaux-de-Fonds, Lausanne, Geneva, Lausanne* (2nd time), and *Berne*, the starting-point. The time lost by the effect of the movement of the levers and armatures of the transferrers is half a second. The current that each office receives from that which precedes, must be registered. After this first operation, the principal offices do the same with the intermediate offices which constitute their district; the result of this must also be registered by each principal office; and each week these registers are sent to the central office, where they are examined. By means of this organization, the advantage is obtained every day: 1st, of knowing the exact hour (Berne mean time), at each station; 2nd, of knowing the condition of the lines before the service commences; 3rd,

* The telegraphic service in Switzerland does not take place during the twenty-four hours of the day, but only from seven in the morning till eight in the evening.

of controlling the state of the batteries; 4th, of being assured that the persons in charge are all at their post.

It follows from this organization that the intermediate offices are obliged to give their despatches in open lines, that is to say, so that they traverse the whole partial line*, in which the intermediate office is included. In this manner, the current always retains the same force, since the resistance remains always constant. But the intermediate office also, as soon as it speaks, occupies the whole line comprised between two principal offices, which is a cause of there being no possibility for two intermediate stations, situated on this line, to be able to give their despatch at the same time. This, it is true, is an inconvenience; but it is small by the side of the advantages that follow from the fact that two intermediate offices are not able to speak together, without being controlled by the principal offices, — from the impossibility that an office shall remain open through forgetfulness, — from the fact that, when a despatch arrives at a principal station, in order to be transmitted beyond, we know at once and without calling whether the line is free or occupied, — finally and especially whether each despatch is always and everywhere given by a current of the same force.

Independently of the organization, that we have just described in detail, M. Hipp has introduced a more considerable modification in the telegraphic system, such as it had been established in Switzerland, by an important change in Morse's apparatus itself. This change consists in substituting for the force of the electro-magnet developed by means of relays and the action of a local pile, an ordinary mechanical power, in order to produce, by means of the stylus, the conventional signs upon the paper. In order to obtain this substitution, we have merely to construct the last two wheels of the clock movement of the ordinary apparatus in such a manner that they shall have the same velocity; they carry upon their axes two wheels cut as a balance or a ratchet wheel, which the smallest movement of the armature, when it is attracted by

* We understand by partial line, that which is comprised between two principal offices.

the electro-magnet, puts into gear with the upper part of a double rack, the axis of which is the same as that of the armature; this rack, in moving to its extremity, communicates the motion of the upper wheel to the stylus, which then presses upon the band of paper. As soon as the magnetisation ceases, the movement of the armature causes the lower part of the rack to come into gear with the lower wheel of the apparatus, which replaces the stylus into its original position. As the movements endure for only a very short moment, in order to write each telegraphic sign, dot or dash, the rack needs present only a very small number of teeth, either in order to guide on the lever, or to be itself brought back, when the electro-magnet no longer exercises any attraction upon the armature. The velocity of the motion depends upon that of the two wheels, which may be rendered such as is requisite for both a prompt and faithful transmission of the despatch. As the result of an experience of two years of the application of this system in several of the offices in Switzerland, M. Hipp concludes that, besides the advantage of dispensing with the relays and local piles, it possesses that of obtaining for the impression a perfectly regular motion, independent of the skill of the clerk, and the velocity of which depends only upon the will of the constructor.

On the same principle, M. Hipp has constructed his portable military telegraph, which would not have been practicable but for the suppression of the local pile and the relays. The pile consists of carbon and zinc pairs, placed in narrow and deep cells, filled with sand moistened with diluted sulphuric acid; if the sand is properly moistened, it acquires sufficient consistency to remain in the cells, even when the latter are inverted. The substantial character of the whole apparatus has been put to the test on many occasions, and particularly when it was sent from Berne to Paris for the Universal Exposition, with the piles charged; it worked perfectly well on its arrival, without its being necessary to touch it in any way. The case which contained the apparatus and batteries of sufficient power for permitting

correspondence along a distance of a hundred leagues, without the intervention of a transferrer, is of a size that permits of its being thoroughly portable, having an inside length of 11 in. with a height of 6 in. and a width of $4\frac{1}{3}$ in.; and presenting a total weight of only twelve pounds. We need scarcely say that the conductors of copper wire covered with gutta percha, intended for establishing communication between the stations, are not included in this weight.

Many other registering telegraphs have been contrived, which are more or less happy modifications of that of Morse. One of the most ingenious is that of M. Froment, which differs from Morse's only in the fact that the electro-magnet acts upon an armature, turning around a vertical axis, and that the signs traced by the pencil and the stylus present horizontal dashes parallel to the direction of the movement of the armature. The despatch is found written in signs by means of a pencil, which is cut in writing, because it turns upon itself at the same time that it executes its movement backward and forward; the pencil is moved in a direct manner, and without intervention, by the armature of the electro-magnet, which is able to execute as many as three or four thousand simple vibrations per minute. The transmission of despatches by means of this telegraph is also very prompt. Nevertheless preference has continued to be given to Morse's system, on account of its greater simplicity.

There is, however, a class of registering telegraphs, upon which we will dwell for a few moments, both because they may in some cases be advantageously substituted for Morse's, and because they depend upon a principle, which admits of a much more varied reproduction of dashes; these are the *electro-chemical* telegraphs. They are based upon the decomposition of cyanide of potassium, by means of a point of steel or iron, serving as a positive electrode, which brings about upon the paper impregnated with the solution of the cyanide, the immediate formation of a cyanide of iron (or Prussian blue) the colour of which, as we know, is very intense. If now there is at the home station a manipulator, the function of which is to make and break the line

current at intervals of greater or less length like the lever-key of Morse's telegraph, we shall obtain at the far station upon the movable band of paper, impregnated with cyanide of potassium, a blue mark, every time the circuit is closed; whilst, when it is open, the iron point will leave no trace upon the paper, although it may even continue to be in contact with it.

Mr. Bain is the first who constructed and employed successfully the electro-chemical telegraph. His alphabet is similar in kind to Morse's; a dot and a dash, and their different combinations. But, instead of employing the lever-key, or an analogous apparatus for transmitting the despatch, Mr. Bain proposed (but the plan in practice has not been carried out) to *compose* it before hand. With this view, by means of a cutting-punch of a particular construction, round holes and dashes, which are merely elongated holes, were proposed to be cut in a long band of movable paper, like that of Morse's apparatus, the perforations being so combined as to represent the despatch that is to be transmitted, of which a complete *facsimile* is obtained. In order to reproduce it at the arrival station, the band of paper, properly pierced, was proposed at the home station to pass between a metal roller and a spring also of metal, which presses the band against the roller; on causing the roller to turn, the band is drawn on by the mere effect of friction, and all its parts are led to pass successively between the spring and the roller. If the paper were not pierced, the spring and the roller would never be in contact; but, as the paper is pierced with holes, every time one of these holes passes between the roller and the spring there is contact between these two metal pieces; and, as the motion of the roller is uniform, this contact lasts for a shorter time when a round hole is passing than when it is an elongated hole. The manipulator being thus constructed, it is merely necessary that the roller should communicate with one of the poles of the battery *, the other being in communication with the ground, and that the

* It is necessary that this should be the positive pole.

line wire should be attached to the spring, in order that the current may be transmitted from one station to the other, whenever the band of paper in passing presents a hole, whilst the current is interrupted, so long as there is no hole, the paper not conducting the electricity. We likewise see that, on account of the greater or less length of the holes, the electric current would circulate during unequal times. Interrupted electric currents are thus produced at the home station, and sent to the extremity of the line, some of them enduring for a little longer time, the others a little less time, and distributed in determinate order, according to the nature of the despatch.* At the far station, the line wire by which the intermittent current arrives leads to a steel point, which rests upon the paper impregnated with cyanide of potassium; the paper is displaced by a uniform movement, as in Morse's telegraph, under the point which remains always in contact with it, sliding along a metal cylinder, which is itself in contact with the ground (*fig.* 389.). When the electric current arrives, and lasts only an instant, chemical decomposition is effected only upon the point of the paper which is at this very moment in contact with the point; it ceases immediately after. And a mere blue dot appears upon the paper. If, on the contrary, the electric current has endured for a certain time, during which the

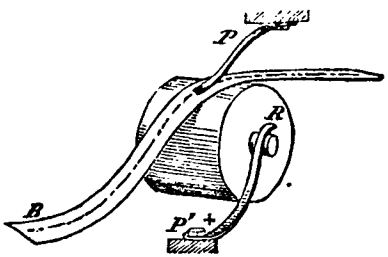

Fig. 389.

* The same system has been applied to Morse's telegraph, in order to transmit the despatch. These papers, thus cut beforehand, analogous to the Vaucanson and Jacquard cards in the arts of weaving, are substituted, as can be understood, for the lever-key, and discharge the office of manipulators, by allowing the current to pass and by interrupting it at the proper moments. M. Siemens has constructed a kind of punch, which permits of the dots and dashes being cut very rapidly upon a paper band, that is to say of writing a despatch very rapidly; this system consists of an apparatus with three keys, in which the first key makes the dots, the second the dashes, and the third leaves the intervals. Notwithstanding these improvements, the employment of the lever-key is preferred in practice, when Morse's telegraph is concerned; and the same is the case in respect to Bain's.

paper has been displaced under the point, a blue dash is the result, and so on. In this manner an exact copy is obtained at the far station of the composition set up at the home station.

In Mr. Bain's first electro-chemical telegraph, the sheet of paper impregnated with the cyanide solution had the form of a large disc, and rested upon a metal disc, to which a very rapid eccentric rotation was imparted by a clock-movement, the motion being so calculated that the iron point traced a spiral upon it. The alternation of dots and dashes is thus found to be reproduced in blue, describing a helix with the turns close together, setting out from the centre and extending as far as the circumference. Notwithstanding the excessive rapidity of the transmission of the despatch that is obtained with this system, since they have succeeded in transmitting as many as fifteen hundred letters per minute, the preference has generally been given to the combination in which a band of paper is unrolled under the iron positive point, in a manner analogous to that which takes place in Morse's telegraph. The despatch is transmitted less rapidly, it is true, but it is more distinct; and there is not the risk, as sometimes happens with the spiral movement system, to omit signs, which requires that it be recommenced.

We should also add that, in the electro-chemical telegraph, as with that of Morse, a relay is generally employed and a local battery, the positive pole of which must communicate with the steel point, whilst its negative pole is led to the cylinder upon the surface of which the moistened paper band is unrolled (*fig.* 389.). The paper must be previously steeped in a solution prepared as follows: *Water*, 100 parts; *nitrate of ammonia*, 150; *yellow ferro-cyanide of potassium*, 5. The presence of nitrate of ammonia renders the paper sufficiently hygroscopic to be always in the state of moisture that is required for telegraphic manipulation.

Mr. Bain's electro-chemical telegraph is in action in England over an extent of 5032 miles, from London to Manchester and from Manchester to Liverpool, &c.; concurrently, it is true with others. It is likewise very much spread in

America, where it is employed for transmitting with very great celerity the debates of Congress and the proceedings of the Assizes in important cases. Notwithstanding its advantages, which consist essentially in a greater rapidity for the transmission of despatches and in less chance of interruption by the imperfection of insulation, since the intensity of the current may be lower, yet the electro-chemical telegraph has had to give place, for ordinary uses, to Morse's telegraph, the manipulation of which is more simple and more convenient, seeing that it does not require either the previous transcription of the despatch or the preparation of a particular paper. However, the electro-chemical process has found another important application in the construction of a particular telegraph, the idea of which, already put forth some years ago by Mr. Bakewell, has been realized in a different manner and with remarkable success by M. l'Abbé Caselli of Florence. We are about to endeavour to make this principle comprehensible, assisting ourselves with the documents which the author has been good enough to place at our disposal.

The registering telegraphs of which we have spoken are either printing telegraphs, or telegraphs which transmit despatches by means of conventional signs. M. Caselli's new electro-chemical telegraph, which he has named *pantographic*, reproduces upon ordinary paper, in coloured characters, a perfectly exact image (*a facsimile*) of the writing or of any design that is required to be transmitted from one station to the other; and this, whatever may be the form or complication of the design or writing. In order to obtain this result, we begin by writing the despatch with the pen, with ordinary black ink, upon a paper, whose surface is covered with a thin coating of tin or silver (silvered paper); it is then placed between two cylinders, which form part of the *transmitting* apparatus; immediately that the circuit of the telegraphic line is closed, the copy of the original appears upon a chemical paper, arranged between two other cylinders, which are also found at the *receiver*.

It would be difficult for us to give a detailed description of the telegraphic system, devised by M. Caselli, and the

first specimens of which we saw at Florence, with apparatus that have not yet entirely the form which the author proposes to give to them; we shall, therefore, confine ourselves to explaining summarily the scientific principles, upon which this beautiful invention rests, making the reserve that is due to the author's rights of property.*

First of all, we should observe that the electric current, which circulates from one station to the other by a single wire, is employed in this system to produce two very distinct effects: namely, to regulate the mechanical movements of the telegraphic apparatus, and to cause the characters of the despatch to come forth, by an electro-chemical action. The most important condition to realize was to attain to a perfect agreement between the movements of the transmitter and those of the receiver. This object has been attained in a very satisfactory manner, by a happy application of the isochronism of the oscillations of the pendulum.

Suppose two equal pendulums of the length of 3·28 feet, each suspended by a horizontal axis, and each loaded with a weight of 44 lbs., which consists of a rectilinear electro-magnet.† These pendulums, placed in the two corresponding stations, constitute the essential part of the apparatus, and are connected together by the line wire. The current, conducted by this wire, must traverse the rods of these same pendulums, in order to accomplish its circuit. Now, if these pendulums are deviated from the vertical through a certain angle, the electro-magnet, with which each of them is furnished, receives a magnetization by means of a local battery, and remains fixed against a wrought iron armature, which it encounters at the extremity of the oscillation. But immediately these pendulums have arrived at this extremity,

* M. Caselli has besides taken out patents for his discovery in the different countries of Europe, especially in France and England.

† M. Caselli, on showing me his apparatus, made me notice that he had adopted for the electro-magnets, fixed at the extremities of the pendulums, the form conceived by M. Cecchi, a distinguished philosopher of Florence, and pointed out to me the advantages that are presented in many cases by this form comparatively with that of the horse-shoe electro-magnets. M. Cecchi's electro-magnet consists of a rectilinear cylinder of iron, terminated by two cubical masses of more considerable dimensions than the cylinder around which the silk-covered copper wire, which is to transmit the current, is wound.

the line current interrupts the circuit of the local batteries; and the pendulums, abandoned simultaneously to the action of gravity, travel toward a second stopping point, situated on the other side of the vertical, at the same distance as the first; there they likewise encounter a piece of wrought iron, which, after having attracted the electro-magnet, fixed at their extremity, allows the line current to pass, the effect of which is to interrupt anew the action of the local batteries; and, consequently to destroy the magnetization, which allows the pendulums to recommence their oscillation, and so on. In this manner the synchronism of the movements of the two pendulums is regulated by the action of the same electric current, and is thus withdrawn from the effect of every disturbing cause.

The line current, after having regulated the movement of the pendulums, at their points of departure, remains at liberty during the whole continuance of their oscillation, so as to be able to be employed in the reproduction of the despatch. The arrangement of the apparatus permits this current to circulate, during all this time, from a platinum point which, in the transmitter, slides in a direct line over the surface of the metallic paper, covered, as we have said, with the despatch written beforehand with the pen, to a metal point (of steel or iron), which, by a similar motion, slides in the receiver along the surface of the paper chemically prepared.* At each oscillation of the pendulums, we see the rectilinear motion of the two metal points repeated in a perfectly identical manner upon both apparatus, at the same time that the papers are unrolled a minute fraction of an inch, by the motion of the cylinders upon which they are placed.† As the ink, with which the despatch is written is a bad conductor of electricity, it is easy to conceive that a modification is produced in the intensity of the line current every time the pla-

* We must not forget that this paper is rolled round a metal cylinder, which permits of the circuit being completed so that the current passes through the paper, between the metal point and the cylinder.

† M. Caselli has succeeded in making the point travel with such rapidity, that the transmission of a despatch, even of very great length, may take place at least as rapidly as by the other most common telegraphic processes.

tinum point of the transmitter encounters a trace of writing; whence there arises at the same time a change in the action that is continually produced upon the chemical paper by the point of the receiver. By means of a peculiar combination, which constitutes one of the newest and most ingenious parts of M. Caselli's telegraphic system, the alteration in the intensity of the current, produced by the resistance of the ink to the passage of the electricity, greater than that which is presented by the metallic surface of the paper, brings about a reversal of polarity in the point of the receiver. From having been negative, it becomes positive, which produces upon the paper a colouring, whence there results an assemblage of coloured lines and points, which reproduce the perfect image of the original despatch, that had been traced by the pen. The instantaneous reversal in the direction of the current produces a chemical effect so rapidly that the most delicate traces of writing and drawing may in this manner be reproduced immediately. We may remark that, so long as the point of the receiver is negative, the current, while still passing, does not alter the colour of the paper; so that the effect of the passage of the point of the transmitter over the marks, traced in ink, is not to bring about the passage of the current upon the chemical paper, because this current was already passing, but simply to change its direction. It would be desirable that M. Caselli should make known the combination, by means of which he obtains this result, and that he would detach this part of his researches from his great work upon the telegraph, that he has devised; the more so as the method, by which he succeeds in so instantaneously reversing the direction of a current, in such a manner that no appreciable time elapses between the passage of the current in one direction and its passage in the contrary direction, might, in its application, lead to very interesting results, particularly as far as concerns the relations that exist between the molecular constitution of bodies, and the effects that are produced upon them by the transmission of electricity.

Magneto-Electric Telegraphs.

In all the electric telegraphs, of which we have hitherto spoken, the source of electricity is a voltaic pile, composed of a greater or less number of pairs, themselves established according to different modes. In general, sulphate of copper batteries, with water slightly acidulated, and composed of more or less numerous pairs, according to the resistance to be overcome, but of inconsiderable dimensions, are employed for the line current. These batteries are able to act for several months, if the precaution is taken of dropping from time to time some crystals of sulphate of copper into the vessel itself, in which the copper of the pair is plunged. For the local batteries, the current of which has a much less resistance to overcome, Grove's or rather Bunsen's pairs are preferred. We have however seen that Gauss and Weber had, at the outset, conceived the idea of employing induction currents for telegraphic communications, and that Steinheil had realized this idea on the large scale. More recently, Wheatstone constructed a dial telegraph, the manipulators of which consisted of a kind of Clark's machine, which for each turn of the handle gave a number of induced currents corresponding with the letters of the receiver; the induced currents being instantaneous, we can conceive that there is no need of an interrupter, as with the continuous currents of voltaic batteries. It follows from this that a simple armature of soft iron, surrounded by a wire covered with silk, movable before a fixed magnet, serves at the same time as the source of electricity and the manipulator. Induction currents have a sufficient tension to overcome the resistance of even the longest line wires, as has been demonstrated by Wheatstone by a series of researches made with much care. A telegraph of this kind, established by himself ten years ago at the station of the Rouen railway, continues to act very regularly; it has, however, the inconvenience of being a little slow, on account of the great number of revolutions which the electro-magnet must execute, in order that the needle of the receiver may pass from one letter to

another. We may add that there is always a manipulator with a divided dial, which carries the letters of the alphabet, like that of the receiver, and a needle the progress of which is likewise perfectly similar to that of the receiver. M. Lippens has modified Wheatstone's magneto-electric dial telegraph, by employing a fixed bobbin in the manipulator, and by making merely the interior soft iron armature movable, which is furnished with parts more prominent than others, that are magnetized on passing before the poles of the powerful fixed magnet. The production of induced currents in the bobbin is the result of this magnetization, which currents act in the receiver by the intervention of the line wire.

The induced or magneto-electric currents have been also applied to the electric telegraph under a form different from that which consists in employing them simply to make the needle of a dial telegraph move on. This form has been contrived by Henley, and applied by the Magnetic Telegraph Company between London and Dublin. The current is produced by electro-magnets, or armatures of soft iron, surrounded by a conducting wire, the poles of which move in a position very near to the poles of powerful permanent magnets represented at A (*fig.* 390.). The electro-magnets are set in motion by

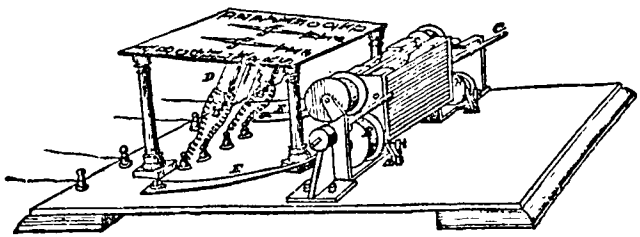

Fig. 390.

levers, that come out on each side of the case in which the whole apparatus is confined; so that the same person is able to make them move by means of his two hands. A spring brings them back to their primitive position, as soon as the hand ceases to act. At each pressure exercised upon the levers there is produced an induced current; and, as soon as

the pressure ceases, another current, likewise instantaneous, but moving in the contrary direction, is developed. The currents thus produced are transmitted by the line wires to the station where the receiver is, and go and traverse the wires of the electro-magnets, which are arranged, as is seen in figure 390., below the slab, upon which the indicating needles are placed. The electro-magnets each act at the moment of their magnetization upon a small permanent magnet, suspended below the slab, but which has the same axis as the indicating needle, to which it is parallel. A deviation of this needle, at the moment when the electro-magnet is magnetized by the induced current, is the result of this; and this deviation remains, from the effect of the attraction of the soft iron of the electro-magnet upon the little movable magnet, until the induced current, moving in a contrary direction to the former, arrives and changes the polarity of the electro-magnet, and at the same time the direction of the deviation of the needle. We are therefore able, at the home station, to make each of the needles deviate in one direction or the other, by pressing upon the levers or ceasing to press upon them, and thus to produce all the combinations of Wheatstone's needle telegraph, which we have described above. Figure 390. represents a double-needle magneto-electric telegraph, which requires two line wires, besides the return by earth. We can have a single needle only; which enables us to be content with a single wire; but in this case, Morse's alphabet is employed with advantage for the transmission of despatches. These signals are engraved upon the dial; a double oscillation corresponds to a dot, and a time of stopping to a dash. In order to produce the double oscillation or dot, the ivory key of the manipulator is pressed upon and immediately abandoned; the pressure upon the ivory key carries on the electro-magnets, by causing them to make a quarter of a revolution, before the poles of the magnets, and thus produces an instantaneous current; the release of the key causes the electro-magnets to return, by means of the spring, to their primitive position, and produces a second instantaneous current, moving in a contrary direction

to the former. This double action brings about the double oscillation, by causing the needle to deviate first to the left, then to the right. In order to cause the needle to make a resting time, the key of the manipulator is held down for a few moments; the deviation of the needle of the receiver endures for a moment, because the magnetism developed in the electro-magnet by the induced current does not cease instantaneously as this current does; and besides, the electro-magnet acts as soft iron; but, when the key rises, the direction of the magnetism changes, and the needle returns to its primitive position.

We may remark that the changes of position of the electro-magnet of the manipulator, in respect to the fixed magnet, may be obtained, not only by a rotatory motion, produced around a horizontal axis, as in Clark's machine; but also by elongating the electro-magnet from the magnet by the aid of a lever; the double movement is produced by depressing in like manner and raising the hand. This second method appears in practice more simple and regular; it has also been adopted in the most perfect magneto-electric telegraphs.

In magneto-electric, as in the other telegraphs, an alarum or bell, for the purpose of giving warning that a despatch is about to be transmitted, is always added to the receiver; it is made to act at the same time as the needle of the receiver; and the noise that results from it coincides with the oscillations of this needle. Besides, magneto-electric currents are very convenient for making these alarums act; seeing that the apparatus, by which they are produced, are always ready to do their duty. This advantage, it is true, exists in a less degree for their employment in telegraphy in general; but they possess the advantage of rendering the construction of the manipulator much more simple, since they are of themselves instantaneous. Finally, it follows from this that they act alternately in inverse directions, which, in practice, prevents the duration of the magnetization of the soft iron, which sometimes does not cease immediately with the current, by which it is brought about; but especially prevents the production of

static effects in submarine and subterranean conductors, which, as we shall presently see, interfere with the rapidity of the transmission of despatches, when ordinary currents are employed.

Conductors employed in Telegraphic Lines. — Simultaneous Transmission of two Despatches by a single Conductor in contrary Directions.

On commencing this Section, we saw that, in every telegraphic system, there are three things to consider: the apparatus themselves provided for transmitting and receiving the signals, — the means of producing the electricity necessary for the transmission of signals, — and finally the mode of communication, or the conductors, by which we are enabled to pass a current from one station to the other. We have dilated sufficiently on the first point; we have been likewise occupied upon the second, in pointing out the various electric sources which are generally employed in the telegraphic stations. With regard to the third point, we have treated upon it only partially and in passing, and we have postponed to a special article the developments that it requires.

We have already seen that there exist three modes of electric communication between two telegraphic stations; namely, aerial conductors, that is to say, wires suspended in the air; subterranean or submarine conductors; and finally the ground itself: we are about to examine successively that which concerns each of these methods.

The wires that are generally employed for aerial lines are iron wire about a sixth of an inch in diameter, covered with a layer of zinc in order to render them less oxidizable. As we have seen, they are supported by poles suitably distributed, and upon which are fixed the insulating supports, sometimes of porcelain as in England and France, sometimes of glass as in Germany and Switzerland; these latter are of bottle glass; they surmount the pole, and are terminated by a kind of button mushroom, also of glass, around which the

line wire is twisted (*fig.* 391.). To the same pole are sometimes fixed several of these glass supports, when there are several telegraph wires to be established between two stations. Figure 392. represents the arrangements which experience has proved, in Switzerland, to be the best; even the dimensions in feet and inches of the different parts of the apparatus and of the distances by which they are separated*, will be found in the figure. In England, each pole is covered with a roof, and carries at its upper extremity wooden arms, upon which are fixed double lines of brown stoneware, through which pass the line wires. There exist also as we have already said, in England and in France, besides the sustaining poles, winding posts, which possess more considerable dimensions than the others; for they must resist the very powerful strain that is put upon the wires, in order to tighten them.†

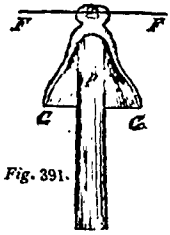

Fig. 391.

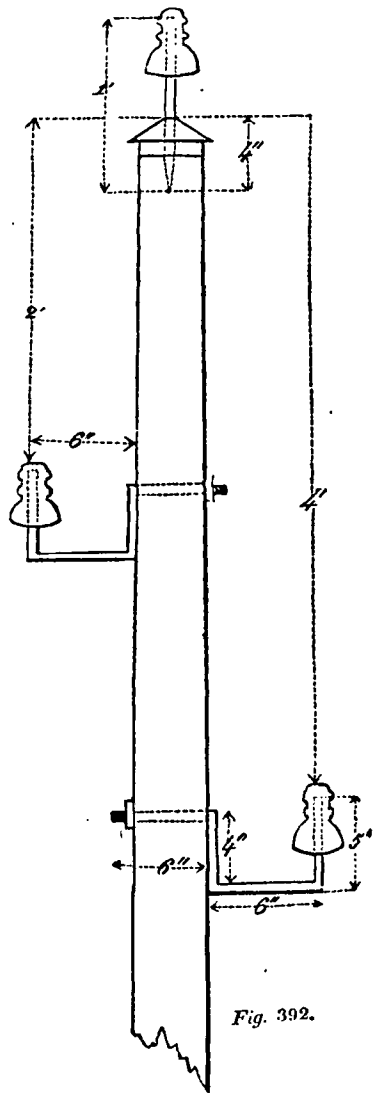

Fig. 392.

One of the inconveniences of the aerial lines is that the

* Comparative experiments made in Switzerland between supports of glass and of porcelain, such as are constructed in France with great care, have given this preference to the former.

† Vide *fig.* 377. p. 365.

conductors on them are exposed to the effects of atmospheric electricity, which, as we have seen on many occasions, is not only able to act upon the telegraphic apparatus and thus to give rise to errors; but which creates the risk also, as sometimes happens, of causing damage, and even accidents, by penetrating, by means of the wires, even into the interior of the stations. The precaution has been taken, in the English lines*, to surmount the poles with a point, which communicates with the ground by a conducting wire; it is true that atmospheric electricity, in escaping by this way, no longer risks damaging the poles; but this precaution does not prevent its acting upon the wires themselves in the interval comprised between two poles, and of finding by means of them an easy way of penetrating into the ground. When, from the appearance of the sky, the symptoms of a storm are recognised, the line wire is placed directly in communication with the ground, by means of a commutator, which allows the atmospheric electricity to escape into the ground; but when the telegraph apparatus is in action, this electricity being unable to discharge itself directly into the terrestrial globe, it is necessary to possess means of obtaining protection against accidents, which may result from the transmission, which is often unexpected, of a powerful electric discharge. With this object in view, Mr. Walker has conceived the idea of establishing upon every wire, both up and down, in each station, a lightning conductor, constructed as follows:—A hollow brass cylinder, C (*fig.* 393.), $\frac{1}{16}$ in. in thickness, is placed in communication with the ground by a thick wire E; it is insulated from the line-wire, which arrives at F, by a disc of box-wood D; a bobbin B B, likewise of box-wood, covered with three or four layers of copper wire, covered with silk, and finer than any of the wires that enter into the formation of the telegraphic apparatus, is placed in the interior of the cylinder, the inner space of which it fills.

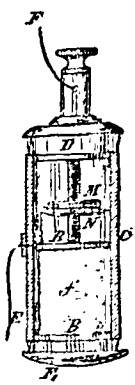

Fig. 393.

* *Fig.* 377. p. 365.

The wire of the bobbin communicates, by one of its extremities, with the wire B, and by the other with the brass disc F_1, situated at the bottom of the apparatus, insulated from the brass cylinder by a disc of box-wood; finally the line wire F communicates with F_1 by means of the wire B, which carries a double nut or spur, M, N, furnished upon its circumference with points, that are as near as possible to the inner surface of the cylinder; points coming out of the upper brass disc likewise approach the metal cylinder C, which is in communication with the ground; other points, coming out of the base of the same cylinder, approach the brass disc placed below. Now this is how matters go on: the line current, arriving at F, passes on, by means of the inner wire B, to the fine wire of the bobbin, which it traverses in order to come out again at F, and to go thence to the telegraphic apparatus, without running any risk of escaping into the ground, the bobbin B keeping the fine wire *f* insulated, and the wooden disc above and below doing the same office for the brass discs and the connecting wires, that pass through them. But, if the line wire is charged with atmospheric electricity, this electricity is able to discharge itself upon the cylinder C, and consequently into the ground, by means of the upper and lower points of the discs F and F_1, which are approximated to the cylinder; more than this, the electricity is also able to escape by the points with which the interior nut, M, N, is furnished; and finally, if any still remains, it will burn the fine wire *f* of the bobbin, in preference to the larger wire of the electro-magnet of the alarum, or of the telegraphic apparatus. This takes place when the discharge of atmospheric electricity is powerful. And when very powerful, it vents its energy upon the conductor, fusing the points, and even the nut and the wire that carries it, while the telegraph apparatus is preserved in its integrity. Mr. Walker quoted the case of a very violent storm, in which the lightning entered into two stations, one of which, being unprovided with the lightning conductors of which we have been speaking, had the wires of its apparatus entirely destroyed and the apparatus themselves very much damaged, whilst the other preserved its apparatus

intact; only the wire of the lightning conductor with which it was furnished was burned. In another storm in which the discharge of atmospheric electricity was less violent, this discharge, after having penetrated as far as the wire of the bobbin, by means of the inner wires, leaped to the cylinder, burning the silk thread and exposing the wire, but without melting it. In a very violent storm on Aug. 14, 1857, lightning conductors were collected in, burned or fused, from instruments which were protected at their expense; whilst many galvanometer coils were collected in, burned and much damaged, from instruments that were unprotected.

M. Bréguet's lightning conductor is constructed after the same principle as that of Mr. Walker; only, in place of the fine wire of the bobbin, is substituted a very fine iron wire, by which two metal knobs, that are placed upon a slab at a distance of 2 or 2½ inches, are connected together. This wire is enclosed in a glass tube in order to be protected from all accident; it serves, as may be supposed, to close the circuit of the telegraphic line, in such a manner that, if there is an excess of atmospheric electricity upon the line, the wire is melted before the knobs are attacked. The apparatus are thus preserved.

Several other kinds of apparatus have been contrived for protecting telegraphic apparatus from the effects of atmospheric electricity. Among the numbers, we will mention the following, which is founded upon the resistance that is presented by alcohol to the passage of the electric current. It consists of a conductor in the form of an arc, or rather of a U reversed, which is placed in the interior of a vessel, filled with alcohol; in the middle and very near to the two vertical branches of this conductor, and parallel to these branches, rises a metal rod, which is toothed, as is also the plate itself, which is in the form of an arc; this rod is terminated in a point toward the summit of the arc, but without touching it, and is in communication with the ground by its lower extremity. In order to arrive at the telegraph, the line current is obliged to traverse the plate, that is, in the form of an arc, which is also well insulated by means of the

alcohol, so that the current cannot be diverted; but, as soon as atmospheric electricity accumulates in it, it is transmitted by means of the points, or closely approximated teeth, to the interior rod, and thence to the ground. Alcohol may be dispensed with; and in this case a slightly different form is given to the apparatus. It is a metal sphere, traversed by the telegraph wire, and maintained in the centre of another sphere of glass, formed of two hemispheres, connected by a large brass ring. This ring is armed interiorly with points that are very near together, and directed toward the centre of the metal sphere to within a small distance from the surface. The two glass hemispheres are terminated by tubes in which the conducting wire passes, being cemented to it. The apparatus is so arranged that this wire is horizontal, and consequently the copper ring vertical; the lower part of this ring is furnished with a metal stopcock, which permits of a vacuum being made in the apparatus if it is judged necessary; the stopcock carries a thread, which is to receive the metal rod, that is intended to place the metal ring in direct communication with the ground; whilst the conductor, which conducts the current of the line wire, and the sphere, which forms a part of it, remain completely insulated. We can conceive that, with this apparatus, the atmospheric electricity which enters into the line wire, and which would be communicated to the telegraph, is transmitted to the ground by the intervention of the sphere and of the points with which the ring is armed. An apparatus similar to the preceding must be placed in each station.

M. Hipp, having remarked that the induced current, due to the action of atmospheric electricity, tends to leap, according to its direction, from a point to a plate, and never from a plate to a plate or from a point to a point, has arranged lightning conductors upon the Swiss lines so that the discharge always finds means to leap from a point to a plate, whatever be the direction in which it is travelling.*

* This arrangement is a modification of that which M. Steinheil had adopted, and which consisted in interrupting the line wire and fixing at each of the separated extremities a vertical copper washer, the two washers being applied

With this view, he interposes in the line wire a metal plate, traversed by two metal points, below and very near to which is a second plate communicating with the ground, and furnished also with two points likewise very near to the former plate (*fig.* 394.).

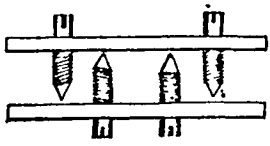

Fig. 394.

These latter forms of lightning conductors, the primitive idea of which belongs to Steinheil, who was the first to think of placing telegraphic apparatus beyond the action of atmospheric electricity, rest upon the principle that this electricity, like that which is developed by frictional electric machines, tends to pass under the form of a spark by the shortest path, even when there is an insulating interval, provided that it be very small; whilst the electric current that is derived from a voltaic battery requires for its transmission a continuous circuit, and will traverse this circuit even were it several hundreds of miles in length, rather than follow a shorter route that might present a slight interruption. This principle, which is a consequence of the difference of tension, that exists between electricity produced according to the former mode and that, which is produced according to the latter, is found to be confirmed by the observation that had been made by Steinheil before he had furnished the telegraphic stations with lightning conductors, that, when the line wire is found charged with atmospheric electricity, this electricity leaps forth in sparks from one end to the other of the wire of the telegraphic apparatus, rather than following all the contortions of this wire, as does the current which is intended for giving signals. However, it may happen that this is not always the case, especially when the action of atmospheric electricity upon the line wire is an inductive action, which produces in this wire an instantaneous current, the effect of which is to produce necessarily a disturbance in the indica-

one against the other, but with the interposition of an insulating layer formed of a thin silk fabric, which allows the discharge due to atmospheric electricity to pass, but not the electric current. The latter arrives at the apparatus by a wire, soldered to one of the plates, and returns into the ground by a second wire, soldered to the second plate, which is fixed to the part of the line wire, that is in communication with the ground, whither the discharge likewise goes.

tions of the apparatus; but yet without producing in them any damage or serious accidents.

Besides the disturbances that may be produced by atmospheric electricity, the aerial wires prevent many other inconveniences, such as the defect of insulation when the poles are moist or when they happen to be in accidental contact with any body that is more or less a conductor; such, again, as the facility with which they may be broken or overthrown, either by the effect of malevolence, or by the action of the wind, or by any other accidental cause; such, finally, as the obstacles which are opposed to their erection, when they are required to traverse inhabited places, and particularly towns or mere villages. Also, as we have already said, the idea had been entertained of substituting for aerial conductors subterranean conductors formed of wires covered with a thick coating of gutta percha. This system, employed in Prussia, was obliged to be abandoned on account of the molecular changes which the gutta percha then employed underwent in the course of time, and which, by permitting moisture to infiltrate into it, establish a communication between the interior wire and the ground, and thus cause the current to be diverted from the desired direction. Ingenious methods had been well devised, which were founded upon Ohm's law, in order to discover the points of rupture; but the frequency of accidents, joined to the difficulty of repairing them, have appeared to present greater inconveniences than those which are more easily surmounted, that are presented by the aerial lines, the establishment of which is besides much more economical. However, in towns, where the length of the circuits is never very considerable, the employment of subterranean conductors presents in so many respects such great advantages, that they have been generally adopted; only, in some cases, simple iron wires, deposited in a bed of bitumen and covered with a layer of the same substance, have been preferred to copper wires covered with gutta percha. These wires are so large that the current does not suffer any resistance; and actual experiments have proved that their insulation was sufficient. However, wires covered with gutta percha care-

fully prepared serve for the same purpose; and they are employed with advantage for the passage of telegraphic lines through tunnels, against the sides of which they are fixed without fear of any defect of insulation resulting from it. All the telegraph companies in England have very long lines of subterranean gutta percha wire laid, in some cases along the railway and in others along turnpike roads, which serve well. The wires of the Magnetic Telegraph Company, which extend from London to the English coast *en route* to Ireland, are exclusively of this kind.

But, if we can do without subterranean conductors, when the establishment of telegraph lines on *terra firma* is the object under consideration, it is not the same in respect to those which are to connect together places separated by the sea. In this case, it is absolutely necessary that the conducting wires should be plunged into the sea, and consequently that they should be enveloped in a good insulating coat; for, the smallest point of contact between the wire and the water of the sea, by causing the current to be diverted, interrupts the telegraphic communication. It is further necessary that these wires be protected not only from the prolonged action of the water of the sea, which might alter the insulating coat, but also from accidents, to which the action of the teeth of fishes or the collision of hard and resisting bodies might give rise. Wheatstone, who, as far back as the year 1840, was the first to conceive the idea that telegraphic lines might be established across the sea, had combined all the means of execution. On January 10, 1849, Mr. Walker submerged an experimental gutta percha covered wire, two miles in length, in the sea off Folkstone Harbour, one end being connected with a wire leading to London, and the other with a telegraph instrument on board a steam-ship. The first message was sent to London at 12.49 P.M., and communication was maintained during the day, until the wire was collected in. On August 28, 1850, Mr. Jacob Brett ran out temporary gutta percha covered wire from Dover to Calais; signals were passed from coast to coast; but the wire, being unprotected, was cut by the rocks and failed next morning. In September, 1851, he submerged the first permanent cable between Dover and

Calais, which is still in use. It was once broken by anchors, but is repaired.

Since this period, several submarine lines have been established: three are already in existence between England and the Continent, one abutting at Calais, another at Ostend, and the other at the Hague. There exist besides two between England and Ireland, others in the seas which wash Denmark and Sweden, as well as in the Bosphorus. During the war with Russia, a line about 400 miles in length had been established in the Black Sea between Varna and Balaclava. Finally, two others have been undertaken, the extent of which will be immense: — One intended to place Europe in communication with Africa, and consequently, by way of Egypt, with the East Indies and probably Australia. Two attempts had been made to accomplish this, but had failed. In September 1855, after submerging sixty-five miles, on entering the great depths the cable ran out with such violence, that it was necessary to cut it adrift and sacrifice it to save the ship and crew. In August 1856, after accomplishing sixty miles, a similar run took place, and the cable was cut adrift; eighteen miles of the submerged length at the shore end were fished up and joined to the 126 miles still on board. This was safely run out; but the 144 miles were just exhausted when the ship was still in deep water, and while the remnant on board was a few miles short in quantity. The cable was now lashed to the ship, which lay by in hopes to hold her own till another length of cable, for which a telegraph message had been sent from the ship, should arrive from London. Rough weather came, and on the fifth day, the cable snapped. A less heavy cable containing four conducting wires was deposited safely, between Bona in Sardinia and Cape Telenda in Algeria, on Sep. 9, 1857; but as it did not quite reach, an extra piece is sent out. The total distance is 145 miles: more than three-fourths of this distance presents a depth of from 1600 to 1700 fathoms, — nearly two miles. The other still more marvellous undertaking is with the view of connecting Ireland with Newfoundland and Nova-Scotia, and thus to permit Europe to communicate telegraphically

with America. Soundings had been made, and a comparatively level plateau of about 400 miles in width, extending from Ireland to Newfoundland, was said to be found. Its surface, nowhere more than a trifle over two miles in depth, was covered with minute organic remains. 1250 miles of cable were coiled on board the Agamemnon, an English screw ship of war; and a like length on board the Niagara, an American ship of war. On the evening of August 7, 1857, the Niagara commenced paying out the cable from Valentia on the W. coast of Ireland; and at 3.45 A.M., on August 11, 335 miles were successfully laid, when the cable parted, while in 2000 fathoms, on account of the amount of retarding strain put upon it in order to check its too rapid run, which had become considerably in excess of the speed of the ship.

We should add, before passing to the description of the conductors themselves, that laying down submarine lines is an operation as difficult as it is delicate. It is necessary to choose, as much as possible, a mean depth of water; for, if the depth is too great, the weight, augmented as in the case of the Atlantic cable, by lateral currents, becomes almost unmanageable; and the strain that is required in order to prevent the cable going out with a run, in all the attempts that have yet been made, has been greater than the cable could stand. If, on the other hand, the depth is too limited, the conductor is exposed to the concussion of vessels, anchors, ice, and shingle, which may alter its envelope.

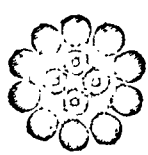

Fig. 395.

The following then is the course that is pursued in order to give to the conductors, or *sub-marine cables*, as they are called, the proper degree of insulation and solidity (*fig.* 395.). The conducting wires employed are generally of copper, about $\frac{1}{16}$ inch in diameter: more than one may be placed in the same cable; from one to six have been included, according to the multiplicity of correspondences to be transmitted. The wire, or each of the wires, if there are more than one, is covered with a

coat or sheath of gutta percha $\frac{1}{12}$ inch in thickness, and placed on in two layers, in order the better to ensure the insulation; for if one of the coats presented a solution of continuity, it is probable that it would not encounter a similar defect in the same point of the superposed layer. When there are several wires, they are arranged one after the other as the elements of a cylinder and tangent in respect to their gutta percha envelope. The placing one of them in the centre is avoided except in the case where there is but one; for then this single wire is necessarily in the centre. The outer circumference, as well as the wires themselves, is furnished with tarred yarn, a material which is not a bad insulator, and which yields to pressure without altering the form of the conducting wires. But that which is essential is the external protecting envelope, which is formed of a variable number of large iron wires, coiled helicoidally, so that the cable, notwithstanding its strength, is able to bend according to the exigencies of the bottom of the sea, when it is deposited therein. This exterior iron envelope in the early cables was covered with a thin layer of zinc, — galvanized, as it is called, in order to prevent oxidation. But experience has shown that this ere long disappears, and that the chemical action of the sea water upon the iron protecting wire is not at all rapid; so that the expense of galvanizing has been avoided in more recent cables. Deposits of sand and shells are not without their use in assisting to preserve the metal.

We shall not enter into further details upon all the ingenious processes that have been put into practice for the construction of submarine cables, particularly in Mr. Newall's factory at Gateshead near Newcastle; nor upon the means employed and the precautions necessary for transporting them and immersing them into the sea. We shall confine ourselves to remarking that unfortunately submarine cables are not protected from all chances of accident. The majority of these accidents are due to the anchors of ships. Several cables have been cut by these anchors.* In order

* This anticipation was unfortunately realized in January 1857. The submarine cables between Dover and Calais and Dover and Ostend were broken.

to obviate this inconvenience, sailors are urged, by notices published in the daily papers, not to cast anchors in the neighbourhood of telegraphic cables the exact positions of which are indicated to them, which they must themselves trace upon their charts.

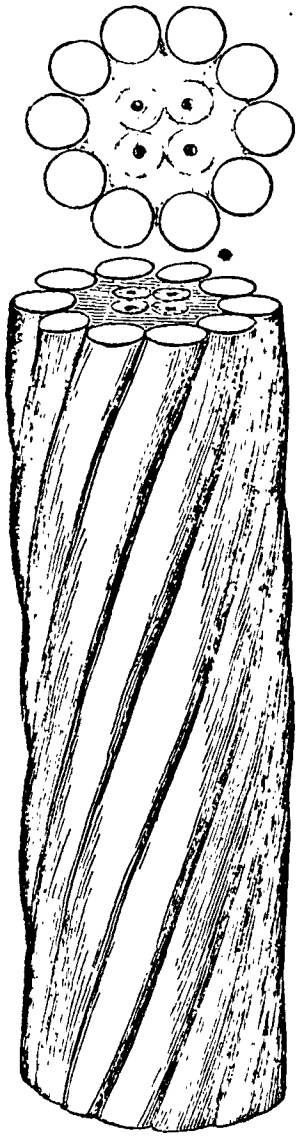

Fig. 396.

Besides this cause of accident, we must not disguise that the cables are often not at depth sufficiently great to be protected from violent agitations of the surface of the sea; and that they sometimes rest upon numerous ridges, so that in great tempests they run the risk of being filed and broken upon these ridges.

Fig. 397.

In order to terminate this subject, we may mention that the cable placed between Dover and Calais (*fig.* 396.) contains four copper wires, and has an outer envelope composed of ten thick iron wires; it is about 25 miles in length, and weighs 8 tons per mile. The Irish cable (*fig.* 397.) is about 90 miles in length, and only weighs about a ton per mile. There is only one internal

Large ships were torn from their moorings in the Downs by a violent tempest, and were pulled up first by one and then by the other cable; but the anchors tore away the cables.

copper wire, and its outer envelope is composed of twelve iron wires, but much thinner than those of the Dover cable. We can conceive the advantage that exists from the cable's containing a great number of copper wires insulated from each other, on account of the facility that hence arises for multiplying the number of despatches, by permitting as many simultaneous and independent communications as there are wires.

The employment of submarine, as well as that of subterranean conductors, occasions a small retardation in the velocity of the transmission of the electricity. This retardation is not due to the length of the path which the electric current has to traverse, since it does not take place with a conductor equally long, but insulated in the air. We have seen* that it arises, as Faraday has demonstrated, from a static reaction, that is determined by the introduction of a current into a conductor well insulated, but surrounded beyond its insulating coating by a conducting body, such as sea-water or moist ground, or even simply by the metallic envelope of iron wires placed in communication with the ground. When this conductor is presented to one of the poles of a battery the other pole of which communicates with the ground, it becomes charged with static electricity, like the coating of a Leyden jar, — electricity which is capable of giving rise to a discharge current, even after the voltaic current has ceased to be transmitted. We shall not return to Faraday's experiments, which we have already explained; we shall content ourselves with referring to those by which Wheatstone has completed the study of this very interesting subject, as well in a theoretical as a practical point of view.

The cable with which Mr. Wheatstone made his experiments is the one that was intended to unite Spezzia upon the coast of Piedmont with the Island of Corsica. It was 110 miles in length, and contained six copper wires one sixteenth of an inch in diameter, individually insulated, and each covered with a coating of gutta percha one-twelfth of an inch in thickness. The cable was coiled in a dry pit in the

* Vol. II. p. 192. *et seq.*

yard, with its two ends accessible; the ends of the different wires could be united, so as to make of all these wires merely one wire 660 miles in length, through which the electric current could circulate in the same direction; this current was itself furnished by an insulated battery formed of 144 Wheatstone's pairs.*

In a first series of experiments it was proved that, if one of the ends of the long wire whose other end remained insulated were made to communicate with one of the poles of the battery, the wire became charged with the electricity of that pole; a charge which, as long as it existed, gave rise to a current which was made evident by a galvanometer: but, in order to obtain this result, it was necessary that the second pole of the battery should be in communication with the ground; if this pole remained insulated, no effect was obtained. However, a long wire, similar to the first, might be substituted for the ground. Wheatstone showed this by taking in the cable two lengths of copper wire, each 110 miles in length. Leaving one of the extremities of each of these partial circuits insulated, he made their other two extremities communicate respectively with the two poles of the pile, taking the precaution of interposing a galvanometer between each of the wires and the poles. In this manner each pole of the battery was armed with a conductor 110 miles in length, insulated at that extremity which was not in communication with the pile, which, as we have said, was itself insulated. As long as one of the poles only of the battery was armed with its long conductor, this conductor was not charged with electricity; but immediately the two poles were equally armed with their conductors, the two conductors became instantaneously charged with electricity, and the strong deviation of the needles indicated the presence of an intense current. If the free extremity of one of the wires was made to communicate with the earth, this wire alone was discharged; the other remained totally charged.

In a second series of experiments, Mr. Wheatstone repeated and varied Faraday's experiments, by interposing

* Vol. II. p. 776. fig. 324.

three galvanometers in the middle and at the ends of the circuit, and by determining in this manner the progress of the current from the order which they followed in their deviation. Thus, according to whether it was with the pole of the battery or with the ground that one of the two ends of the galvanometer was first made to communicate, the other end being placed in communication with the ground, or with the pole of the battery an instant after, the galvanometers were seen to be deviated in the order of their distance from the battery or in the inverse order. If the two poles of the battery were connected by the long conductor of 660 miles, but taking the precaution of dividing it into two portions equal in length, it was observed, on connecting the two free extremities of these two portions in order to close the circuit, that the galvanometer placed in the middle was first deflected, whilst the galvanometers in the vicinity of the poles were not deflected until later. The reverse was the case, if, after having connected the two free extremities of the middle, and having placed one of the ends of the long conductor in contact with one of the poles of the battery, the experiment was finished by bringing the other end into contact with the second pole. All these effects are in accordance with what we have already seen and said in reference to Faraday's experiments.

A third series of experiments has shown Wheatstone that a continuous current may be obtained by placing a galvanometer in the circuit of the long wire of an electric cable, of which one of the ends is insulated whilst the other communicates with one of the poles of a battery whose other pole is connected with the ground. This current is due to the uniform and continual dispersion of the statical electricity with which the wire is charged along its whole length, as would happen to any other conducting body whatever placed in an insulating medium. On placing the galvanometer very near to the pole of the battery, it may be proved that the intensity of the current thus produced is approximately proportional to the length of the wire that is added beyond the galvanometer. In fact, for 0 miles of wire added 0° of

deviation are obtained; for 110 miles, $6\frac{1}{2}°$ of deviation; for 220 miles, 12°; for 330 miles 18°; for 440 miles, $23\frac{1}{2}°$; for 550 miles, 28°; for 660° miles, 31°. If the place of the galvanometer is changed, the current is the more feeble in proportion as it is interposed at a greater distance from the pole of the battery; if it is at the very extremity of the long wire, the current becomes null. Finally, the intensity of the current depends only upon the length of the wire that is placed beyond the galvanometer, the length of that which is found interposed between the galvanometer and the battery exercising no influence. Thus 220 miles of wire placed beyond the galvanometer, bring about a deviation of 12°, as well if the galvanometer is directly in communication with the pole of the battery, as when it is separated from it by a wire of 440 miles in length. This result proves to us that, whatever be the length of the wire attached to the insulated pole of a battery, this wire is charged with electricity to the same degree of tension along its entire length.

The retardation that occurs to the transmission of electricity by submarine cables, and which we have been analyzing both in its manifestations as well as in its cause, is of no great importance for ordinary telegraphic communications. It is the more so when the question is the determination of longitudes, as we shall see at the end of this Chapter: it likewise renders very difficult, if not impossible, the simultaneous transmission of two despatches in contrary directions, which has been tried with success, as we are about presently to mention, with aerial telegraph wires.

We may remark in passing that the preceding experiments completely confirm the theories that we have put forth in our Second Volume, upon the manner in which the propagation of electricity is brought about in conducting bodies, and upon the mode of liberation of electricity in a voltaic pair, which requires, for the chemical decomposition necessary to the manifestation of this electricity, that the two contrary electricities shall both equally find an escape. It is in fact impossible to charge any conductor by placing it in communication with one of the poles of a battery, without

the other pole communicating also with a great conductor, or with the ground.

We are here led very naturally to say a few words upon the part played by the earth when it is employed as a conductor in the operations relating to electric telegraphy. We have already seen that the idea of employing the earth as a conductor between two telegraphic stations, realized for the first time by Steinheil, had permitted the suppression of one of the conducting wires, and thus the realization of a great economy and simplicity in practice. It had been at first supposed that the ground played the same part as the conductor for which it was intended to be a substitute, and that there was established between the two poles of the battery placed in communication with the earth, even when they were at a great distance from each other, a veritable electric current, transmitted through all the interposed conducting matters, and which the earth always contains in greater or less proportion. It is true that the terrestrial globe cannot be considered as being in its nature as perfect a conductor as a metal, but, on the other hand, its bad conductibility is found to be more than compensated by the immensity of its section. We may therefore consider the earth as presenting a null resistance to conductibility*; only we must admit that electric currents are able to cross each other in

* An important experiment of M. Bréguet's shows, in fact, that this resistance is null. A battery being at Paris, one of its poles communicated with the earth by means of a wire, terminated by a large plate, plunged in a well: the other pole communicated with the line wire, and the end of the latter, at Rennes, plunged in like manner in a well; thus, in this case, the circuit was formed half by the earth and half by the wire. A circuit entirely metallic was also procured at pleasure with copper wires, each extremity of which, at Paris, was united to one of the poles of the battery, whilst at Rennes the two other extremities were united together. Similar operations were made at Rennes, where a battery was also situated. By means of two zinc-galvanometers M. Bréguet measured the intensity of the current at Paris and at Rennes, when a current traversed the copper wire and the earth, or the two copper wires united. He then found that the intensity of the current in the former case, namely, when the earth is substituted for one half of the conductor, is double what it is when the current returns by a second wire similar to the first. M. Matteucci, on his part, had arrived at the same results. He had found that when the current went by the copper wire from Pisa to Pontedera, and returned from Pontedera to Pisa by the earth, its intensity was the same as when the two poles of the battery were immediately united by a single copper wire, as long as that by which the two stations were connected. These experiments, and a great number of other similar ones, enable us, therefore, to admit that the resistance of the earth to electric conductibility is null.

all directions, and at every instant without affecting each other. Further than this we must suppose that, between two stations extremely far apart, such as Paris and Berlin, there is a series of decompositions and recompositions of all the interposed molecules of water; and that the positive electricity, for example, that is introduced into the ground at Paris, will not be able to be neutralized except by the negative arising from the same battery, but brought by the telegraph wire into the ground at Berlin; a neutralization going on, from molecule to molecule, through all the conducting sections that are found in the terrestrial globe between these two stations. It is likewise necessary to admit, when the positive and negative poles of several batteries are plunged at the same time in the ground at great distances from each other, that the positive electricity of each pole, in order to become neutralized, goes and seeks for the negative electricity of the pole belonging to the same battery, even though this pole might be much more distant than the negative of another battery. This species of predisposition of the two electricities to neutralize each other only when they arise from the same source, appears to us an hypothesis equally contrary to logic and to observations.

We must therefore have recourse to another explanation of the part played by the earth in the phenomena of electric conductibility, — an explanation, which flows very naturally from the fact, observed by Faraday and Wheatstone with electric cables. This fact is that of a vast reservoir, — of a species of drain, — which sucks up and absorbs at the two extremities of the wire the free electricities which the battery, or any apparatus that is the generator of electricity, sends into it. By the very fact that this electricity is lost or escapes away, there is an electric movement, and consequently a production of a current. M. Magrini, in experiments made with long, well insulated telegraph wires extended from Milan to Monza, had already shown that an electric current might be obtained in a wire, of which one only of the ends communicated with a source of electricity, whilst the other remained insulated. But in this mode of operating some

defect of insulation might be feared. This fear entirely disappears in the experiments of Faraday and Wheatstone. These latter very clearly show us that it is enough to put into communication with one of the poles of a battery the end of a conductor of very great dimensions, the other extremity of which is insulated, in order that this conductor, in becoming charged, may be traversed by a current, the presence of which is indicated by the deviation of the needle of a galvanometer. The same phenomenon takes place with the earth, with this difference, that the terrestrial globe being a conductor of infinite dimensions, the current is able to endure as long as the communication of the pole with the ground takes place.

M. Matteucci, who has greatly directed his attention to the conductibility of the earth, had made the curious remark that, when the electrodes are plunged into the ground to a suitable depth, the resistance of the interposed layer increases exactly with its length, according to the recognized law for ordinary conductors; there is not even any difference, when the layer is very thin, between its resistance and that of the same layer of earth or water contained in an insulated vessel. But, if the distance between the electrodes becomes considerable, the resistance of the terrestrial bed diminishes very rapidly; even at the distance of from 60 to 100 yards the current ceases to diminish; at greater distances its intensity increases until it becomes equal to that, which would be found with the circuit entirely metallic. This result is always verified for distances of ten or twelve miles. The increase of the current with the length of the terrestrial bed is independent of the nature and form of this bed; it was before having arrived at the length of the bed at which the resistance ceases, that the influence was observed of the nature and form of this bed over this same resistance. This observation of M. Matteucci's clearly shows us that the earth is able to play two very different parts in the transmission of currents. It is able to discharge the function of an ordinary conductor, when the electrodes are very near to each other; and then the resistance which it opposes to the

current, increases with the length of the interposed terrestrial bed; but when the distance between the electrodes attains to a certain limited dimension, the earth acts as a reservoir, which absorbs the electricities liberated at each of the poles; its resistance then disappears, and the intensity of the current depends on nothing more than the resistance of the conducting wire alone; so that the intervention of the terrestrial globe presents the double advantage of permitting the economy of one line wire, and of rendering the current twice as strong as it would have been, had it been made to return by the second suppressed wire.*

Besides, many other facts of a different kind demonstrate, that it is not necessary, in order to obtain a current, to reunite the two contrary electricities produced by the same electrical apparatus; but that it is sufficient that one of the two electricities be absorbed. Thus it is that, when the outer coating of a Leyden jar is placed in communication with the ground, we are able to obtain a discharge in the air, similar to a current, by furnishing its inner coating with a point. Now, one has never dreamt of saying that the two electricities transmitted, one into the earth, the other into the air, are reunited by the contact of the ground and the air. Moreover, M. Soret and I have demonstrated that water may be decomposed by causing it to be traversed by the electricity which leaves the outer coating of a Leyden jar, that is charged by its inner coating. Now, it is very evident that, in this case, the current by which the decomposition is produced does not arise from the reunion of the two contrary electricities liberated by the electrical machine, by which the jar is charged.

* This difference between what takes place, when the electrodes are near together and what takes place when they are far apart, may seem extraordinary at the first moment; however, on reflecting upon it, we easily conceive that in the former case the molecules interposed between the two electrodes, not being so numerous, may constitute the electric chain by the effect of the mutual neutralization of their opposite electricities, which is preceded by their polarization. When the electrodes are very distant, this communication between them can no longer take place; and they are then discharged, by means of the bed with which they are in contact, into the entire mass of the terrestrial globe.

The part that is played by the earth in the transmission of telegraphic despatches is, therefore, in accordance with a very great number of phenomena of the same kind, which have demonstrated to us that the propagation of electricity, and consequently the production of an electric current, may take place in a conducting body, as well when this body is placed in communication with another, charged with an excess of one of the electricities only, as when it is found placed between two excesses of contrary electricities.

We may add, that when the terrestrial globe is employed for bringing about the circulation of a current in an insulated conductor, one of the extremities of which communicates with one of the poles of a battery and the other with the ground, whilst the second pole of the battery also communicates with the ground, care must be taken to establish these communications well. With this view, the conducting wires that abut in the earth are terminated in large metal plates, generally of copper, which are also buried as deep as is convenient in wells, or in the most moist parts of the ground that can be found. The gas and especially the water pipes of towns are advantageously employed for obtaining good communication with the earth. And fish-jointed rails are valuable, in country stations especially.

The question that we have just been discussing as to the part played by the terrestrial globe in the *transmission* of electric currents, is connected with that which we have already discussed incidentally, — namely, whether the same conductor is able to transmit at the same time two electric currents in two opposite directions*; we solved it negatively when the conductor in question was of finite dimensions, and requiring that all its molecules, interposed between the two contrary electricities, should be successively polarized and discharged, so as to constitute the current. It was impossible for us to admit that the same molecules could be polarized and discharged at the same time in opposite directions; we have besides seen that

* Vol. II. p. 396.

the phenomena, which seemed to demonstrate this simultaneous transmission of two contrary currents, were explained quite as well by admitting that there was no effective transmission. But it is no longer the same when the conductor has dimensions, infinite relatively to the quantity of electricity put into play; this conductor, then acting as an absorber, is evidently able to transmit or rather to have the appearance of transmitting in all directions equally, and consequently simultaneously in the same direction, electrical currents having opposite directions, as actually takes place with the terrestrial globe. On the other hand, with a wire like a telegraph wire, this is not the case. However, various means have recently been discovered for transmitting simultaneously two despatches, by a same wire in two opposite directions; but, as we are about to see, in describing the process employed, it does not follow from this that two currents circulate at the same time in the wire in contrary directions; it is merely an appearance due to a combination, the veritable effect of which is to permit at the same time, at each station, the manifestation by the apparatus, with which this station is furnished, of the proper signals, by means of the local batteries.

MM. Gintl, Wartmann, Siemens, Halske, and Edlung have been equally occupied in solving the problem of the transmission of two despatches by a same wire in two opposite directions; they arrived almost at the same time at its solution, by processes which, while entirely differing in their details, possess in substance a great analogy. Some have applied their process to the electro-chemical telegraph, others to Morse's, which is of little importance; for, when once the question is solved, it is evident that it is so for every telegraph system. Also the only question with us will be to know how two relays, situated at two different stations, which are to transmit and receive simultaneously each a despatch, may be made to act properly, at the same time; when once the relays execute each the motions proper for indicating the despatch received, the rest follows of itself.

In order to obtain this result, two wires, covered with silk

and perfectly similar, are wound in contrary directions to each other around the electro-magnet of each relay, — an arrangement from which it results that, when two equal currents in the same direction are traversing them parallelly, there is no magnetization, and consequently no movement in the relay. These two wires are soldered together by one of their ends; this point of soldering or contact is in communication with a metallic piece, which we will call A; of the two other free extremities, one B communicates with the line-wire, the other C may at pleasure communicate with the ground, or with a conductor D, by the intervention of the wire of a rheostat, to which the necessary length is each day given, in order that its resistance may be equal to that of the line-wire. The conductor D leads to the ground, and may be put into communication with one of the poles of a local battery P. It follows from this arrangement that, if one of the poles, the positive for instance, of this local battery is made to communicate with the soldered point A, at the moment in which the other pole is made to communicate with the conductor D, the current is established, bifurcating at the point A into two parts, one of which, following the line-wire, returns by the earth to the departure station, and the other of which, coming out at C, returns to the negative pole by the intervention of the wire of the rheostat of the conductor D. These two portions of the current do not act upon the relay of the home station; since, as we have seen, they are rendered equal. Everything is arranged exactly in the same manner at the second station; it is also the positive pole of a battery P′, which leads to the soldered point A′ of two wires wound in opposite directions around the electro-magnet of the relay of that station. When the negative pole of the battery P′ is put into communication with the ground, by means of the conductor D′, the current of this battery is also divided into two parts, one of which comes out by the extremity B′ of one of the wires, in order to traverse the line-wire, and to return by the ground to the starting-point; and the other comes out by the extremity C′ of the second

wire, in order to return to the negative pole, by the intervention of the wire of a second rheostat, placed also at that station, and of the conductor D′. The communications of the negative poles of the batteries of each of the stations with the ground may be established or interrupted at pleasure by the person who is transmitting the despatch, by means of a lever-key; it is by acting upon this lever-key, as is done in Morse's telegraph, that signals are transmitted; and, at each station, the lever-key may be acted upon in an independent manner, without any anxiety as to whether it acts at the corresponding station. The following is the mode in which things takes place.

We act at the first station without acting at the second; consequently without the communication with the conductor D′ of the negative pole of the battery P′ existing at that station, or without the rheostat being in the circuit. The current, coming out from the former, traverses the relay, which is placed there, without acting upon it, as we have seen; one of its halves traverses the line-wire, enters at B′ into the wire of the electro-magnet of the relay of the second station, arrives at the soldered point A′ of the two wires, enters into the second and comes out at C′ in order to penetrate thence into the ground, and return to the negative pole of the battery of the first station. It is easy to see that this current, which has not acted upon the relay of the first station, must act upon that of the second; since, in consequence of the arrangement of the two wires, it traverses them *successively* in the same direction; whilst, when the current traverses them *parallelly*, bifurcating between them, its two portions traverse them in contrary directions.* Things take place in the same manner when in order to send a despatch from the second station to the first, the negative pole of the battery at the second station is made to commu-

* Nothing is more easy of comprehension than,—when two wires are wound in opposite directions around a bobbin, and these wires are united by their extremities, which are situated on the same side, the current that enters by the free extremity of one of the wires, and that comes out by the free extremity of the other, will circulate in the same direction around the bobbin, during its whole course, through both wires equally.

nicate with the conductor D′, and consequently with the ground, and at the same time with the extremity C′ of the second wire of the relay, by the intervention of the rheostat. The current bifurcates between the two wires of the relay, and does not therefore act upon it; one half accomplishes its circuit through the wire of the rheostat, the other half traverses the line-wire, in order to go and act upon the relay of the first station, by traversing successively the two wires, in order to return thence through the ground to the battery P′. Thus then the transmission of despatches is easily accomplished, both from the first station to the second, as well as from the second station to the first; and, even when the current traverses the relays of the two stations, it is always only the relay of the station, whose lever-key is not touched, that is affected, the relay of the departure station not being so, on account of the two equal and contrary currents that traverse it.*

Now, what takes place if we close at the same time the circuits of both local batteries at both stations, by establishing simultaneously at both of them, by means of the lever-keys, the communication between the negative poles and the conductors D and D′ respectively? It is evident that the positive poles of the two batteries, which abut at A and A′, are found united by one of the wires of each relay,—the wires A B and A′ B′, and by the line-wire B B′; whence it follows that this arrangement of the circuit will be traversed by two equal and contrary currents; or rather that no current will be established in them. Thus from the fact that, at both stations equally, the circuit is closed at the same time, the two relays that are situated in it are set in motion; since in both of them one of the two equal currents, which mutually neutralize each other, is destroyed; but what is remarkable is, that the

* We should remark that, at the station, where the lever-key is at rest, the extremity C or C′ of the second wire of the relay communicates directly with the ground; whilst, as soon as the lever-key is lowered, this communication is interrupted, by substituting for it that which takes place with the conductor D or D′, by the intervention of the rheostat. We have already seen the lever-key fulfil this double office.

relay of the first station acts by the effect of the current, which, traversing the wire A C, returns by the rheostat to the negative pole of the battery P, and consequently by the effect of the current of its local battery, as the relay of the second station acts also by the effect of the current of its local battery. Thus the arrangement of the telegraphic system is so combined that, when the transmission of the two despatches is simultaneous, one of the equal currents of each relay is annihilated, which destroys equilibrium and enables the non-annihilated current to act.

To sum up: there will be then a transmission of signals, whether we act successively or simultaneously upon the lever-keys of each station: in the former case, by the direct effect of the line-current transmitted from the station that sends, to the station that receives; in the latter case, by the annihilation of the two line-currents, which should travel in contrary directions, if that were possible; and by the preponderant action, which results from it, of one of the two contrary currents, which traverse the electro-magnets of the relays, and which, but for this, would neutralize each other equally at each of the two relays. Hence we comprehend that the transmission of despatches in one of the two directions is completely independent of the transmission that takes place in the other, and that these two transmissions may be accomplished at the same time.

The principle of the method consists, as we have said, in the division of one current into two individual circuits acting in reverse directions upon the electro-magnet of the relay. MM. Siemens and Halske, who employ the rheostat in order to render the two partial currents equal, take care to place at each station a multiplier with two wires, by means of which they know the length that must be given to the rheostat in order to bring back to zero the action exercised by the local battery upon the electro-magnet. M. Wartmann employs two local batteries, each acting separately upon one of the wires of the electro-magnet, and one of which must have greater tension than the other, in order that

the two partial currents may be equal. This method, to which Mr. Wartmann has on his part arrived, is analogous to that which M. Gintl had pointed out with the same object in view.

In conclusion, we may remark that the system which we have been describing, although extremely ingenious, presents still some practical objections. Besides the difficulty, not insurmountable it is true, but very great, that is experienced in rendering the two currents equal at each relay, there exists a real inconvenience in the impossibility under which we are placed, of interrupting the transmission of a despatch, in order to demand an explanation or to correct an error, without there being a risk of a great confusion resulting from it, since the interruption cannot be simultaneous on both sides. It is therefore probable that, all things considered, it will be preferred to have a double wire and a double apparatus between the stations that have many communications together, in order that these communications may be successive, instead of having only one wire and one system of apparatus, able to serve for simultaneous transmissions in opposite directions.

We shall terminate this subject, by saying a few words upon the attempts that have been made to apply the telegraph to the security of railways, by placing the trains in communication with the stations toward which they are moving. An ordinary telegraph, specially adapted to the service of the railway, can be employed for transmitting, from station to station, the announcement of the arrival of a train; but there has been a desire to render these indications more certain and more frequent, by causing them to come from the train itself. Mr. Tyer's system has been tried on certain lines in England of establishing circuits traversing stations, and which are closed at certain points only, when the train in passing causes the rails to bend, or presses down a spring. The current then acts upon warning apparatus — *indicators*, which thus show the passage of the train at certain known points; and enables the persons on duty to give timely notice by signals to the engine-driver, if the line is obstructed. Instead of

employing, for closing these circuits, the flexion of the rails, M. Du Moncel has employed the tender, or any waggon of the train, to put in communication for a moment the two extremities of the insulated wire cut by the way, by means of a metal arc also insulated carried by this waggon. M. Bonelli has proposed to place in connection, in a permanent manner, either the train and the station, or two trains travelling on a same road. His process, which was applied on the railway from Turin to Genoa, consists in placing an iron plate all along the road between the two rails; it is supported four inches above the ground by insulating supporters of baked clay. A metal slide, fixed to one of the carriages of the train, places in communication the conducting bar and a telegraph apparatus placed in the waggon; and this same apparatus communicates with the ground by the axle of one of the wheels, the wheel itself, and the rail. A battery, acting in the station, has one of its poles connected metallically with the bar; the conductor, which comes from the other, passes into a telegraphic apparatus, and thence plunges into the ground. Hence, it is merely necessary to lower the slide in order that the circuit may be closed, and that the train consequently may be in correspondence with the station; we can conceive that the same arrangement enables two trains, both of which are in motion, to be placed in telegraphic communication. The changes of road, the crossings of rails, and level crossings presented difficulties for the establishment of the conducting bar; in these several cases M. Bonelli makes it pass under ground, enveloping it with gutta percha.

On some English railways, nowhere more so than on the South-Eastern, the movement of trains is entirely regulated by telegraphic signals. On the railway in question, the conditions under which trains or engines are allowed to move, are that: —Every train leaving or passing a station is signalled *out* to the next station, and must not go on till the *out* signal is taken. Its arrival is signalled back to the last station, and no second train is allowed to follow until the first has arrived; for no two trains are permitted to be on

the same length of railway between two signal-stations at the same time. A train is considered *in* when within the protection of the semaphore-signals of the station, and the telegraph permission for a second train to follow, refers only to the open line, as far as the previous train is concerned, and extends only to the distant signals of the station. On approaching the station the train is subservient to the visible signals.

When train-signalling was in its infancy, the wires and instruments (Cooke and Wheatstone's single or double needle) were used in common for general correspondence and for train-signals; and the object was indifferently accomplished, since either class of correspondence on busy lines continually interrupted the other. When the importance of perfect train-signalling was realised, special wires were erected for this purpose alone, and a simple system of apparatus was organised.

Mr. Walker employs for train-signals the signal-bell shown in *Figs.* 398. and 399.

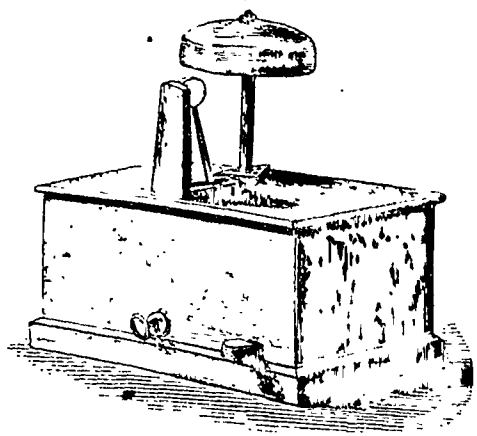

Fig. 398.

It consists of a large electro-magnet, with a movable armature, carrying a stem and a hammer, which latter strikes on a bell by the direct force of magnetism. It

is provided with a contact-maker,—a spring, the depression of which causes a current to circulate. The bobbins are 4 in. × 3 in.; and are filled with ten pounds of covered copper wire, No. 16 or No. 18. The core is of five-eighth inch iron. The armature and appendages weigh 2¼ oz. One feature in which this instrument differs from the telegraph in common use, is in the employment of wire of large size for the electro-magnets, instead of the usual very fine wire. Electro-magnets thus constructed are active at all the required distances (which vary from half a mile to seven or more miles); and the hammers strike loud blows. *Fig.* 399. shows the arrangement of the different parts. *Fig.* 398. shows the bell with its case over it, and the solid rest against which the hammer falls dead without rebound, so that no false action shall occur. The battery employed is zinc-graphite, and is excited with a solution of 1 sulph. ac. + 8 or 10 water. The plates, 7½ in. × 3 in., are placed in stone

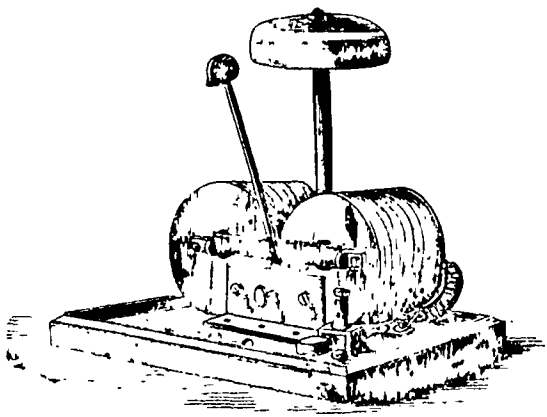

Fig. 399.

pots that contain about a quart, the zinc standing in a gutta-percha slipper, containing mercury. Batteries of this kind will do their work untended for half a year and longer.

Sets of from eight or ten to thirty or thirty-five cells are employed according to the distance.

The *language* consists of blows on the bell; the number of blows varies according to the train-signal to be given. The distinctions required for ordinary purposes being few, the bell language is very appropriate, from its addressing the ear, from its simplicity, and from the facility with which the signals are given and taken. *One* blow is for the starting of an UP train; *two*, for a DOWN train; *three*, for the arrival of a train; *five*, for stopping all trains; *six*, for testing. This is a general code: other forms of code are used for protecting level crossings and junctions; but the fundamental signals of the "general code" are in most request. A signal *given* by one station is not complete until *taken* by the other station repeating it. The bells are almost invariably in pairs. Sometimes an intermediate bell is inserted (at a level crossing for instance) which is actuated by every current that passes between the extreme stations, and gives the signals seriatim. This intermediate station hears, but does not make a reply to signals. In another case, an intermediate station requires to make special signals to either terminal station; in this instance, it is furnished with battery power, and a *pair* of contact springs to its bell. The connections are, in most cases, so arranged that the home station rings the distant bell, its own remaining dumb, for a signal sent. Now and then both bells are allowed to sound with every signal, whether given or taken. The signals and the times are entered in a book.

Mr. Walker has made each pair of bells not only available and under the control of the signal men at each terminal station, but also available to the persons in charge of trains at any intermediate point on the open railway, so that should a train or engine break down or be in difficulties, on any portion of a railway, where these bells are in use for the ordinary purposes of signalling trains, the guards or drivers will be able to ring them, and call for assistance to the stations on either side of them, without its being necessary for them to have with them any telegraph or battery, or any electrical apparatus whatever; nor to have any ac-

quaintance with telegraph arrangements or telegraph language.

This is accomplished by presenting the same pole,—the graphite for example,—of the battery at each of the terminal stations to the line-wire; the other pole,—the zinc,—being in permanent connection with the earth. Under these circumstances, neither of the two currents that are presented to the circuit is able to circulate, being opposed by a reverse current of equal value. The wire is in a null state,—in a condition as it were of tottering equilibrium; the arrangement is:—

Earth, Zinc, Graphite, Bell, LINE-WIRE, *Bell, Graphite, Zinc, Earth.*

In making a signal from either terminal station, the spring which connects the line-wire with the bell is depressed upon a stud, that leads directly to the earth, and the home bell and battery are thus excluded from the circuit, the line-wire going direct to earth. The arrangement thus becomes:—

Earth, LINE-WIRE, *Bell, Graphite, Zinc, Earth.*

Under these circumstances, the current of the one remaining battery is free to circulate, and an ordinary train-signal is made.

But, if the line-wire is connected with the earth at any intermediate point, two distinct circuits are completed; and each bell rings by the current of its own battery. This arrangement may be thus expressed:—

Earth, Zinc, Graphite, Bell, Line-wire, Earth, Line-wire, Bell, Graphite, Zinc, Earth.

In a rough way, a loose wire may be twisted to the telegraph line-wire, and contacts be made with the rail, as many times as the bells are required to sound; but in practice, a contact-spring is provided on the telegraph posts at each quarter mile, and connected with the line-wire; and a stud is connected with the earth by a wire leading from it either to the rail, or to a lump of metal buried in the wet soil. The contact-spring is counter-sunk in the pole; and a cover painted red is nailed over and made water-tight. When a train is in distress, the persons in charge are required to strike

off the cover and depress the spring ten times, which will cause both bells to strike ten times; and this will be the distress signal.

Another manner, in which Mr. Walker applies current equilibrium to telegraphy, is in making the batteries of *both* stations available for *each* signal, made by either station;—and in this way is able to dispense with half the cells at each station, and so to reduce the cost. Instead of excluding the home battery from the circuit, in order to make a signal, the signalling station inverts the position of the battery in the circuit, and then causes the current of both batteries to move in the same direction, and conspire in producing the signal. The arrangement then is:—

Earth, Graphite, Zinc, (Bell), Line-wire, Bell, Graphite Zinc, Earth.

This interchange of connections is made by a slight addition to the contact-maker; by which also the home bell is excluded from the circuit when required. When half the battery power is in this way at each terminal station, the distress signal, if made mid-way, may sound both bells as before,—but, if elsewhere, only the bell nearest to it may sound; and thus indirectly is information conveyed of the probable position of the train that is in distress.

This system of train signal-bells has been in use for six years; and is established throughout from London to Dover, and extensively elsewhere on the South-Eastern district.

The proposition for employing balanced currents for telegraphic purposes was first made in 1848 by M. Botto. The batteries were equally balanced, the home station was to remove one or more cells from the circuit, according to the signal he wished to send; this would destroy equilibrium, and a current would circulate. The far station would then remove cell after cell until equilibrium was restored, which would happen when he had removed the *same number* as his correspondent; the number withdrawn was to indicate the signal sent.

In cases where it is deemed prudent to retain a record of the various bell-signals sent and received, so that, in the

event of any mischance, a reference may be made, Mr. Walker is proposing the employment of the Globotype telegraph, invented by Mr. McCullum. *Fig.* 400. will give an idea of the very simple principle on which this instrument

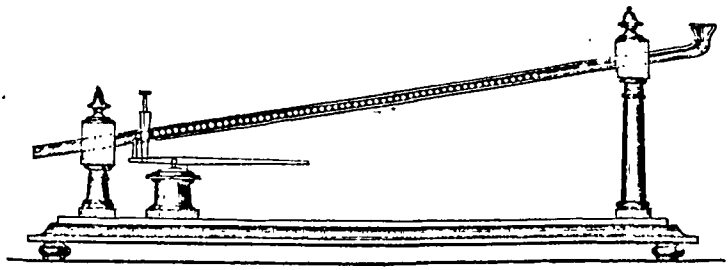

Fig. 400.

depends. Tubes of glass or metal contain a series of small balls, of a given colour, white, red, or black. Near the lower end of each tube is placed an electro-magnet; the armature carries a lever, which is furnished with a detent that enters the tube, and retains the balls. For each motion of the armature one ball only is able to pass. The lower end of the tube is properly connected with a dial, of which *fig.* 401. is an illustration.

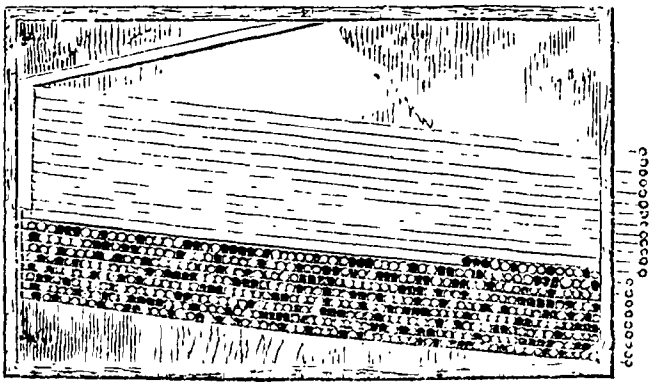

Fig. 401.

The balls run down by mere gravity: and, when the lower row is filled, a brass slip by being pressed in, opens the second row; and so on.

In the arrangement for recording train-signals, the tubes are of metal and of sufficient length to contain balls enough for one day's work; and they are, for convenience sake, coiled round. There are three tubes, — for white, spotted, and black balls. A white ball is to fall into the home dial every time the contact-spring is pressed down, The white balls are evidence that the signal man has done *his* duty. If double or treble sets are seen, it is evidence that he has failed to get attention the first time. A black ball is to fall into the dial every time the bell strikes. The black balls, therefore, are evidence that the apparatus was in order, and has done *its* duty. The spotted balls will fall every five, ten, or fifteen minutes, as the case may require; and will mark off the time into intervals. One of the wheels of the station clock will carry the necessary number of pins, for making the contacts for dropping spotted balls. The dial will be furnished with twenty-four lines or grooves, one for each hour; and will require no attention from the signal-man. The balls will be guided through a lift to the first line; and a clock-contact will shift the lift hour by hour from line to line.

Employment of the Electric Telegraph in Scientific, and more particularly in Astronomical Observations.

The various processes and apparatus, that we have been describing, have been devised with a view especially to the services which the telegraph may render to social relations. However, science, and more particularly astronomy, have found it a valuable auxiliary for certain observations, which require a simultaneity of operations in very distant places, or an immediate communication between two very distant points. Thus it is that, by means of the electric telegraph, we are able to know at the same instant the state of the atmosphere on several points of the terrestrial globe, — valuable data for meteorology. Thus also are we enabled to transmit the announcement of a hurricane in the direction according to which it is propagating itself, so as to give time to those who run the risk of suffering by it, to take the necessary precautions.

But, as we have said, it is astronomy that has especially derived advantage from this instantaneous mode of communication.

Mr. Airy, Director of the Royal Observatory at Greenwich, is of all astronomers the one who has directed his attention most continuously, and with the greatest success, to this application of the electric telegraph, in which he was promptly seconded by the co-operation of other astronomers, and in particular of M. Quetelet and M. Leverrier. He has established at Greenwich a complete system of voltaic batteries always charged and ready to enter into action, each having its special destination; and composed of a greater or less number of pairs, according to their destination. From each of these batteries are led copper conductors, covered with gutta-percha, which lead into an apartment, whence, by means of commutators and other suitable apparatus, the current receives the desired direction. Thus one of the conductors causes an astronomical clock to move; another serves to write down the passage of the stars, by means of dots, traced by a system analogous to Morse's, upon a paper fixed round a cylinder, to which a helicoidal motion is imparted, and upon which is traced beforehand a spiral line to serve as a base line; another current is used for transmitting, by means of the telegraphic wire, Greenwich mean time to the different telegraphic stations in England, and especially to show the hour of 1 P.M. in London and at Deal, at the very moment of 1 P.M. at Greenwich, by the dropping of balls placed in elevated situations visible afar off. There exist also a considerable number of other applications to astronomical wants of an analogous nature, devised by Mr. Airy. We could not point them all out without exceeding the limits within which we are compelled to confine ourselves; besides, they are based upon the same principles as those which have occupied our attention for so long a time, and differ from them only in certain mechanical details in the construction of the apparatus, which are easy of comprehension. We will therefore confine ourselves to insisting upon that application, which appears to us to present the

greatest interest, and which has most occupied Mr. Airy, namely, the determination of the difference of longitude between places situated at great distances from each other. But, before entering on this subject, let us be allowed to point out the admirable order, which has presided over the arrangement of the different batteries, as well as the arrangement of the conductors in the Greenwich Observatory. It is easy to recognise in them the spirit of order, as well as the penetrating sagacity, of the skilful director of the observatory, who has introduced into this part of his vast scientific department the same precision and the same regularity which impart so great an authority to the Greenwich observations, by the confidence which they inspire.

In 1852 the wires were established for the purpose of connecting the Greenwich Observatory with the principal telegraphic offices in London; through them first, in 1853, with the observatories of Cambridge and Edinburgh; and, subsequently, with those of the Continent, both with that of Brussels, and then with that of Paris.* We shall enter into

* The wire, that comes from Greenwich, passes under ground as far as Blackheath; there it can be placed in communication with one of the subterranean wires which lead to the electric cable that connects London with Paris through the sea. By means of a commutator, arranged in an iron box, which is itself secured in a wall of Greenwich Park, the telegraph wire, that leads to Paris, and that which leads from the observatory, may be placed directly in communication; so that the signals may pass directly from the observatory to Paris, and reciprocally. For the ordinary uses of the telegraph, the commutator is so placed that London and Paris may be connected together; which allows of telegraphic signals being transmitted without the intervention of the observatory. Finally, if Greenwich and London are connected, the signals may pass between the observatory and London, and any place with which London is connected. Thus, in order to establish a communication between the observatory of Greenwich and that of Brussels, it is necessary first to establish communication between Greenwich and London; and to accept of the courtesy of those employed in the London telegraph office at Cornhill, for establishing a temporary communication between the segment of the Paris telegraph wire, to which the wire that comes from Greenwich and that which comes from Brussels lead, after the precaution has been taken of suppressing the connections of these wires with the earth. Mr. Airy had hoped that the determination of the difference of longitude between Paris and Greenwich, would be the first application that might be made of the establishment that we have just been describing. During the summer and autumn of 1853, negotiations had been opened on the subject with the Bureau des Longitudes; but the illness of M. Arago, and other causes interrupted them, which, as M. Quetelet was found to be very desirous of engaging in the enterprise, induced Mr. Airy to decide upon commencing with the determination of the difference of longitude between Greenwich and Brussels.

some details upon the determination of the difference of longitude between Greenwich and Brussels, which we extract from the memoir inserted by Mr. Airy in Volume XXIV. of *The Memoirs of the Royal Astronomical Society of London.* We shall not dwell upon the preliminary details relative to the determination of the correction of the clocks,—to the manner of closing the circuits, which must be done by different persons than those charged with observing the signals. We shall confine ourselves to remarking, before giving the results of the operation, that the observations had been divided into two series, in one of which a Brussels observer observed the telegraphic signals, as well as the transits, by the correction of the Greenwich clock, whilst a Greenwich observer was making corresponding observations at Brussels; the observers were then interchanged, in order to make the second series of observations in the same manner. We may also add that the signals consisted of the movements of a magnetized needle produced by the closing of the circuit,—movements which were exactly the same at both observatories, and upon which all the attention of the observers was to be exclusively concentrated. Finally, it is not useless to remark that, as it had been agreed, by interchanging the observers, to eliminate the errors arising from personal equation and affecting both the signals of observation as well as the transits observed, they were not placed in a condition to obtain a comparison between the different manners of observing; it was only accidentally that a few comparisons were made.

The first important determination to be obtained, was that relative to the comparison of the hours of the electric signals, observed at Brussels and at Greenwich, which were not accompanied by observations of the transit of stars. These observations could not give the difference of longitudes, but they were necessary, in order to make known the time employed by the electric current for its transmission from Greenwich to Brussels, and reciprocally. Another point essential to know, but of a purely astronomical nature, was the determination of the elements necessary for calculating

the errors of the transit instrument, and the clock-errors for the days during which the observations of the difference of longitude were made.

These precautions being taken, two methods were followed for arriving at the determination of this difference. In one, the transits of fundamental stars were employed; it was not necessary that the stars observed should be the same in both observatories. In the second method two lists of stars were prepared, the one preceding, the other following the signals The positions of the stars were not supposed to be very exactly known; but, before employing them for correcting the clock, the lists of the stars observed in the two observatories were compared, and all those were rejected which had been observed in one observatory only. In this manner, only the transits of stars absolutely the same were compared; and the accuracy of their recognised right ascensions was unimportant. The transits observed were corrected numerically for the effects of errors of the instruments, the elements of which, as we have said, had been determined. With regard to the clock-errors, they were obtained by comparing the transits corrected with the calculated positions of the stars; and these errors, duly reduced to the time of each signal of observation, were applied to the times given by the clock for the signals. The difference of these times for the two observatories gives the apparent difference of longitude; that is to say, the comparison of the sidereal times of the telegraph signals observed at Brussels and at Greenwich. In order to obtain the real difference of longitude (still affected by personal equations*), it is necessary to take the mean of the separate results, that are obtained in equal numbers, by making a similar number of Greenwich observations at Brussels, and reciprocally of Brussels observations at Greenwich; in order to eliminate the influence of the time employed by the current for passing over the distance by which the two observatories were separated, the following steps were taken: — The signals given by the Greenwich battery to Brussels

* We have said how this cause of error was guarded against, by means of the interchange of the observers.

give the excess of the indication of the Brussels above the Greenwich clock, *increased* by the *time of transmission.* Signals given by the Brussels battery to Greenwich give the excess of the indication of the Brussels clock, *diminished* by the *time of transmission.* By noting the results of the signals given by each station in turn, and letting $+x$ in the one case and $-x$ in the other represent the time of transmission, and by interpolating the equations so as to correct any error in the rate of the clocks, the Astronomer Royal obtained, as the final result for the time employed by the current for traversing the distance by which the two observatories are separated, $0''{\cdot}109$; — a value, which depends upon 2616 observations. This duration, which, if the velocity of the current were uniform, would lead to a velocity of 2500 English miles per second, since the telegraphic distance between Greenwich and Brussels is 270 miles, would be very great compared with that which we have obtained by other methods.*

But we should observe that from Greenwich to London, and from London to Ostend, the telegraphic line is situated entirely under ground or under water, which, as we have seen †, occasions a considerable retardation in the rapidity with which electricity is propagated at the first moment when the circuit is closed. It is therefore very probable that the retardation observed is almost entirely due to the part of the line that passes under ground or under the water; and that the retardation from Ostend to Brussels, a route along which the wires are in the air, is insensible in practice.

With regard to the difference of longitudes between Greenwich and Brussels, the means of 1104 signals give the final result of $17'\ 28''{\cdot}9$; this is the best that under present circumstances can be obtained for the determination of the element in question; it is, moreover, identically the same, according to the remark of M. Quetelet, as that which is furnished by the observation of the solar eclipse of May 15, 1856.

* Vol. II. p. 192.

† See Wheatstone's experiments (p. 441.) in connection with electric cables; and those of Latimer, Clark, and of Faraday, Vol. II. p. 194. *et seq.*

In 1854, conjointly with M. Leverrier, Mr. Airy likewise determined the difference of longitude between the Greenwich observatory and that of Paris. The method was the same, and consisted in the employment of telegraphic signals for the comparison of the simultaneous state of the clocks of the two observatories. The signals themselves resulted from the deviation of two magnetized needles placed in the two stations, and set in motion by the action of the same current. The signals were observed by the precaution which the astronomer took of noting the time of the clock at which they appeared; but as it was not possible, in a general way, to calculate upon an accuracy greater than two tenths of a second, in the appreciation of the instant at which a signal thus observed appeared, it was necessary, in order to arrive at a high degree of precision, to employ a great number of signals. M. Faye, as M. Leverrier remarks, would have preferred that recourse should have been had to the method of coincidences for the comparison of the sidereal clocks of the two observatories. By allowing a series of simultaneous signals to be beaten, in each of them, by means of a mean time pendulum, the epoch could have been observed of the coincidence of these signals with the sidereal pendulum. The relative state of the two pendulums would have been exactly concluded, because the coincidence would have been observed of the two beats with a precision far superior to that with which a fraction of a second of time is estimated directly.

This method, based upon the coincidence of pendulums, was likewise proposed and put in practice by M. Thaler of the observatory of Upsal. By furnishing the extremity of the rods of the two pendulums with small steel points, which plunged into mercury at the moment when the rods were perfectly vertical, M. Thaler closed his circuit, so that the coincidence of the two pendulums, whatever was their distance and their difference of rate, might be indicated by the establishment of a current, which it was easy to employ, either by the magnetization of an electro-magnet, or in any other manner, so as to give a signal. The simultaneous

states of the clocks at the moment of the coincidence were determined either by the observers themselves or by registers. It is necessary to remark that the current was interrupted as soon as the pendulum-rods, or one alone of them, ceased to be in the vertical position.

M. Leverrier, on his part, while still recognising that the determination of the state of the clocks by the method of coincidences would constitute a progress in the problem of longitudes, was led to think that the question would be still more simplified if it were possible completely to do without the determination of the relative state of the pendulums; and this by registering upon the same chronograph the observations made in the two stations, as has been done for some years in America. This method could not in principle present any objection, since the registration is made by the intervention of a current that traverses a telegraphic wire, the length of which is a matter of indifference. But, in practice, it presented great difficulties, which have been only gradually surmounted in an apparatus, the construction of which has been entrusted to M. Liais. Upon a band of paper, set in motion by a train of wheels, an iron point traces equidistant divisions, corresponding to the movements of a sidereal pendulum, and by the action itself of this pendulum, one or two points permit the observers to mark by dots, by means of the electric current, upon this same paper band, the instants in which a same star passes the various wires of their instruments. The difference of the stations in longitude is hence concluded, as may easily be understood. There are many precautions to be taken in the employment of this method, which has, however, enabled M. Leverrier to determine, with remarkable accuracy, the difference of longitude between the observatory of Paris and the Depôt of War, where a meridian telescope had been established.

Application of Electro-magnetism to various Apparatus.

In the two preceding Sections, we have described the applications of the electro-magnetic properties of the electric

current to the production of motion in general and to telegraphy in particular. Independently of these two classes of applications, there exist a great number of apparatus, more or less in use, founded upon the same principles. We are about to make them known, by dwelling more particularly upon those which seem to us more to deserve the fixing of our attention.

Electric Clocks.

The invention of electric clocks was a natural consequence of that of telegraphs. Several philosophers, Messrs. Wheatstone, Bain, Steinheil, realized nearly simultaneously the problem, the solution of which was to multiply at pleasure the indications of a single clock, which might telegraph of itself the hour, the minute, the second, marked upon its own dial. There is no need of insisting upon the importance of this application of electro-magnetism, which permits of our making all the clocks of any establishment, of a city, of a railway, move in coincidence; and by means of which the measure of time might be conducted through the streets of a city, as is done at the present time for water and for gas.

Before making known the apparatus by which this invention has been realized, we will speak of what may more justly be styled electric clocks; namely, clocks in which the motive force — the weight or spring in ordinary movements — is an electro-magnetic force. The latter invention does not evidently present so much interest as the former; and besides, the electricity applied in this case, in order to develope a motive force, brings with it the inconvenience of a continual expense, which the employment of a weight or a spring that is wound up does not necessitate. However, apparatus both very ingenious and remarkable for their simplicity have been invented, and they have been made successfully to go with great regularity. *Fig.* 402. represents Bain's pendulum, one of the first that were constructed, and in which the action of two permanent magnets upon a helix or bobbin, traversed by a current, sustains the motion of the pendulum. A conducting wire, communicating with the

extremity of the spring to which the pendulum is suspended, passes behind its rod, is wound in a spiral around the bob, so

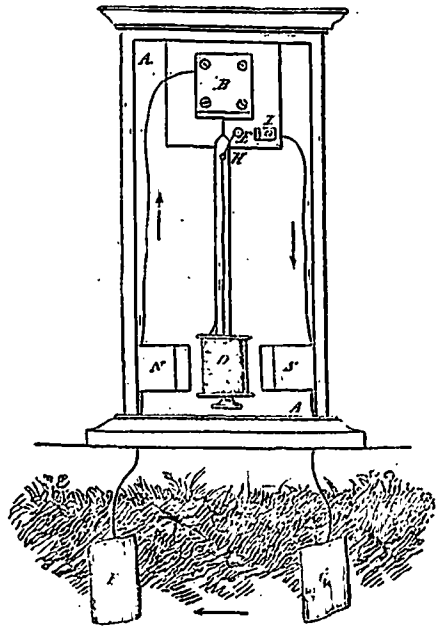

Fig. 402.

as to form a horizontal helix, and ascends again to *H*, where it is connected with a spring, which carries at its extremity a small platinum ball, *E*. *N* and *S* are the north and south poles of two magnets between which the pendulum oscillates. Finally, the poles of the battery which, in the figure, is composed of a plate of zinc and one of copper buried in the ground, communicate with the points *I* and *B*. Every time the pendulum in oscillating arrives at the right extremity of its course, contact is established between *I* and *E*, the circuit is closed, the current passes, and the bobbin is repelled to the left, both by the repulsive action of the pole *S*, and the attractive action of the pole *N*. The backward and forward motion of the pendulum is transformed into a rotatory motion, by means of pallets acting upon a toothed wheel, as takes place in the receiver of the dial telegraph.

Other electric clocks have been constructed, resting upon the same principle; that is to say, in which the direct action of an electro-magnetic force sustained the oscillations of the pendulum; but, we may conceive that the constancy of the impulse thus given depends upon the constancy of the magnetic force, and that this impulse must consequently vary with the intensity of the electric current. The going of this apparatus has been successfully rendered independent of this element, by giving to the pendulum impulses always equal, by the effect of a weight that acts upon it, and by employing electricity merely to bring about the action of the weight. The following is the ingenious mechanism invented by M. Froment (*fig.* 403.). The pendulum, *a b*, is suspended by the spring *r* to a fixed metallic piece, and carries on its side a small screw, *e d;* the wire surrounding the bobbin of the electro-magnet *g* has one of its ends at *f*, and the other communicates with the movable piece *h;* this latter is terminated at its extremity by the weight *i;* and it is when the screw *e d* comes into contact with it, that the circuit is closed. The armature of the electro-magnet is a piece movable around *k*, the range of which is regulated by the two points, between which its extremity *j* is situated. Finally, the two poles of the battery are at *n* and *p*, and the wires *m m'* complete the circuit, causing the current to pass, as we shall see immediately, into the indicating apparatus. Suppose the pendulum to be deviated to the right from its vertical position; it returns to it, and passes beyond. The screw *e d*, arriving at a certain height, raises the weight *i*, which the armature of the electro-magnet had hitherto supported. Setting out from this moment, the current passes, the armature is attracted, its extremity *j* descends; whence it follows that, when the pendulum after having attained the extremity of its range returns to the right, the weight *i* finds nothing but the armature lower down to sustain it, and consequently accompanies the pendulum for a longer time in descending than in rising. The result of this is an impulse given to the motion at each oscillation; and we can conceive that it would be possible, by regulating the range of the armature, to preserve

to the oscillation exactly the desired duration, that of a second, for example. By means of the apparatus, that we

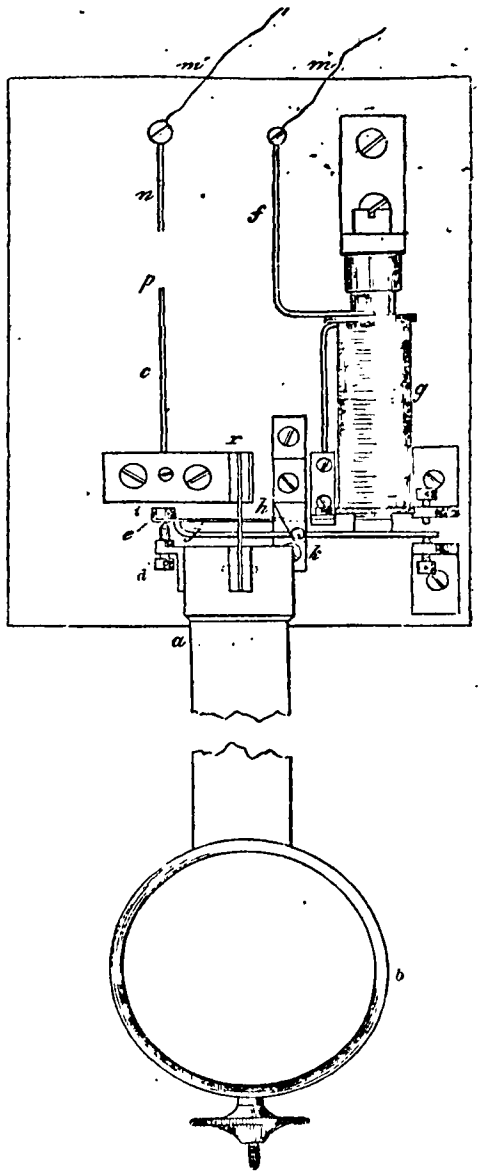

Fig. 403.

have just been describing, we have then a current which is established, and which ceases once per second. The conducting wire, whose two extremities we have represented at m and m', passes into the indicating apparatus (*fig.* 404.), and there forms a double electro-magnet, before which is a movable armature. When the current passes, the armature is attracted, and it acts upon a system of articulated levers, the last of which drives on a wheel, furnished with sixty teeth. This arrangement possesses the advantage of substituting a gradual pressure for the shock that would have taken place, had the armature acted directly upon the wheel. Finally, a spring which presses upon the teeth serves at the same time as a moderator for the velocity, and as a stop after the passage of each tooth. Since the wheel has sixty teeth, and the current passes once per second, it will make one turn per minute; and hence we can understand that an arrangement analogous to that of ordinary clocks gives minutes and hours to the wheels, the axes of which carry the hands. We should remark that it will be easy to have as many indicating apparatus as may be desired, and that their number and their respective distances will be limited only by the intensity of the current.

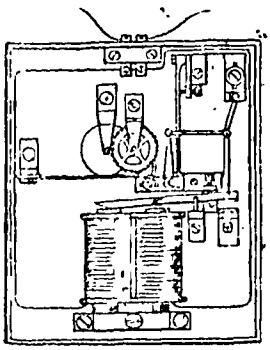

Fig. 404.

We have described Mr. Bain's clock, for its priority in this application of electro-magnetism; and that of M. Froment, the mechanism of which appears to us the most ingenious and satisfactory. We may mention also the names of MM. Robert-Houdin, Vérité, and Garnier, as those of authors of various improvements in this class of applications.

We now come to the question, of which we have first spoken; and we are about to study some of the electro-magnetic horary or counting apparatus, which move simultaneously with a type-clock and which merely transport, so to speak, its indications. In describing M. Froment's electric clock, we have already studied the process which he follows

for transmitting to any number of counting apparatus the isochronous beats of his pendulum. When the clock has a spring or a weight for its motion, the principle of transmission remains no less the same; that is to say, the movement of the type-apparatus opens and closes the circuit of a current at intervals of equal times; and this current, passing through the indicating apparatus, causes their hands to move on by a mechanism, analogous to that employed by M. Froment.

Figure 405. represents Mr. Bain's system. In the middle

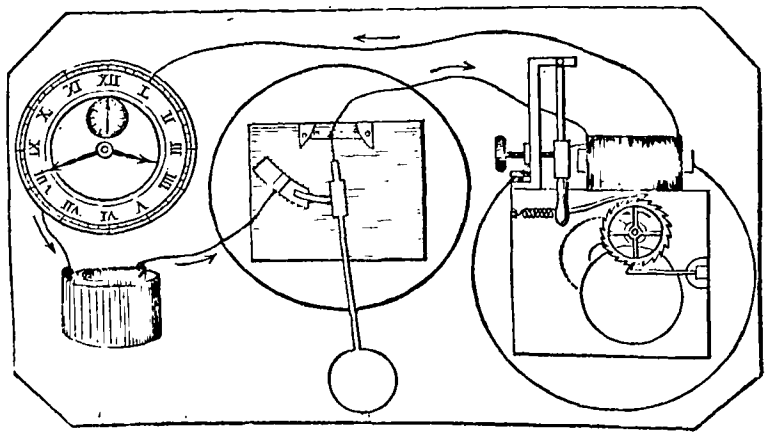

Fig. 405.

an ordinary clock is seen to be drawn, visible at the back, and whose pendulum beats seconds. At the right and the left, are represented two horary apparatus, one with its dial, the other with the details of the mechanism that causes it to move. Finally at the left is the battery, which is here composed of only a single pair. A very light spring is fixed to the pendulum; and at each oscillation it arrives in contact with a metal piece, to which is attached one of the extremities of the conductor, whilst the other communicates with the pendulum rod, so that the circuit is found to be closed once per second. On the other hand, by the mere inspection of the figure of the counter, we see how, at each magnetization of the electro-magnet, the armature draws on the hook, which catches into a fresh tooth, and how, when the magnetization

ceases, the spring causes the wheel to move on the whole extent of this tooth.

In order to make a great number of electric clocks move at the same time, a powerful battery would be necessary. We can make the electricity act successively in each of them, which requires a much less intense current. But then they no longer give the indication of seconds. Figure 406.

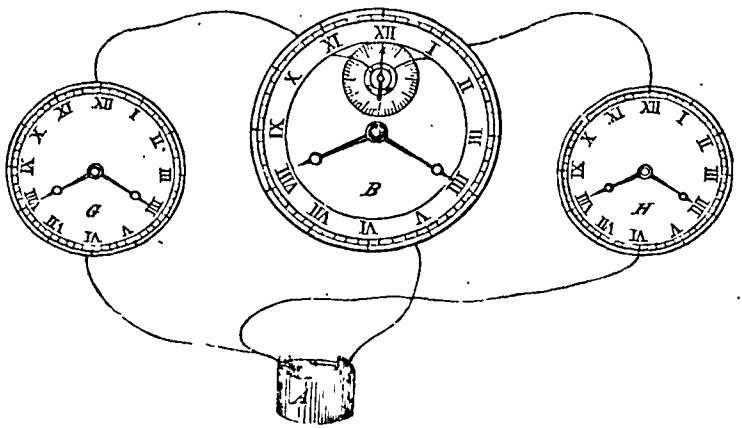

Fig. 406.

shows the regulator, or type clock, upon the dial of which is fixed a small ivory circle with metallic sectors, in number equal to that of the indicating apparatus, which we desire to have the power of arranging. Upon this circle, and in contact with it by a small spring, the seconds' hand moves, which on the other hand serves to close the circuit. Every time the hand passes over a brass sector the current traverses the indicating apparatus corresponding to this sector. Now, the seconds' hand accomplishing one revolution per minute, it follows that, pending the duration of a minute, the current passes once into each of the indicators, which causes a wheel in each, having sixty teeth, to advance one tooth, which wheel carries the minute hand.

We are indebted to M. Paul Garnier for a system of electric clocks adopted at the present time in many places. The primitive clock is composed of two different wheels; one

as in ordinary clocks, is intended to maintain the motion of the pendulum; the object of the other is to produce the rupture and the passage of the current; and it is subject to the progress of the former in such a manner that its last axis, which carries a fan, represented in *fig.* 407., follows the

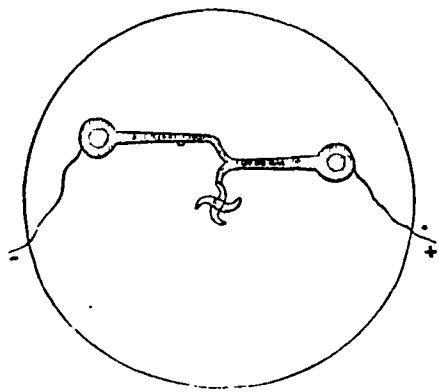

Fig. 407.

motion of the scape wheel. Two levers, through which the current must pass, come into contact when the fan raises that which is resting upon it; and, in this manner, the current passes in equal intervals of time in the electro-magnets of the indicating apparatus. We have represented one of those that are employed by M. Garnier (*fig.* 408.). This

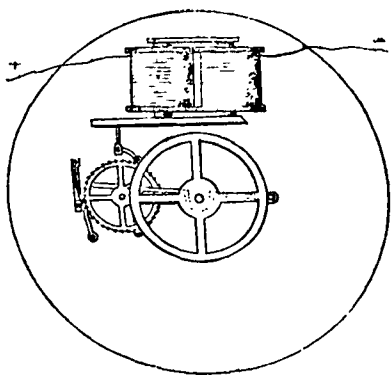

Fig. 408.

figure shows sufficiently of itself how the ratchet wheel

passes on one tooth every time the armature is attracted. M. Garnier arranges his apparatus by transmitting into each indicating apparatus only a current derived from the principal current, which is passing in the type-clock. In this manner, one of them may cease acting without the progress of the others being affected by it.

We may terminate this subject by saying a few words upon a mechanism whose purpose is to make ordinary clocks or time-keepers agree, by regulating them each hour, by the passage of an electric current from a regulator clock. *Fig.* 409. repre-

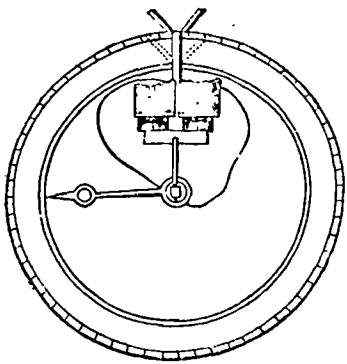

Fig. 409.

sents one of these clocks, the dial of which has been removed as well as the minute hand, which latter carries near its end a small pin perpendicular to the plane of the dial, the purpose of which is that it may be caught in the fork that is seen to be represented. This fork usually occupies the position traced in dotted lines; but at the last second of each hour, the regulating clock causes a current to pass to all the electro-magnets of the other chronometric apparatus; the armature being raised in each of them, draws on the fork, which assumes the position indicated in the figure, and which, by the intervention of the pin, brings the minute hand exactly on the noon point.

It remains for us to describe Shepherd's electric clocks, which are well known in England; which are fitted up in the Royal Observatory, Greenwich; and are employed in con-

nection with the distribution of time signals and dropping of time-balls, as described in the preceding Section. This is essentially an electric-clock,—electricity being the motive power of the pendulum and of the prime-clock, as well as the means for distributing time to other clocks. Figure 410. is a perspective view of the pendulum,—its remontoire escapement,—and the arrangements by which electro-magnetism is made to be its maintaining power. To the left, also, is shown the arrangement by which a dial and its batteries are connected with the pendulum. P is a portion of the pendulum rod, which has a mercurial compensation, and is suspended from the metal frame D by a spring in the usual way. The letters, in order from A to F, show the course of the voltaic circuit from the silver, S, of the battery to the zinc, Z. The wire A connects the silver with the beginning of the coil B; the end of the coil is connected with the bed or brass plate C, which is in metallic connection with the frame D, and consequently with the pendulum rod suspended thereto; in its right-hand swing the pendulum continues the circuit to an insulated spring, E, whence it is completed to the zinc of the battery by the wire F F. The face of the spring E, and the surface of the pendulum that comes into contact with it, are furnished with platinum contacts. Mr. Walker has had a pendulum of this kind in action for nearly six years, with these contacts unimpaired. From this description it will be seen, that at the end of each right-hand swing the circuit will be completed, and the iron horse-shoe (whose ends, N S, rise slightly above the bed-plate C) will be magnetized. The magnetization will cease as the return swing toward the left commences. The contact is adjusted to endure for a small fraction only of a second, so that there may be no unnecessary consumption of battery power.

The process by which this alternate magnetization and demagnetization becomes a maintaining power to the pendulum of uniform force is extremely simple. A small weight is raised to a uniform height by means of the magnetism, and falls through a uniform distance by gravity. The figure shows the position of the scapement, while the pendulum is

making its right-hand swing, and just before it makes contact with the spring E, and completes the circuit. When the

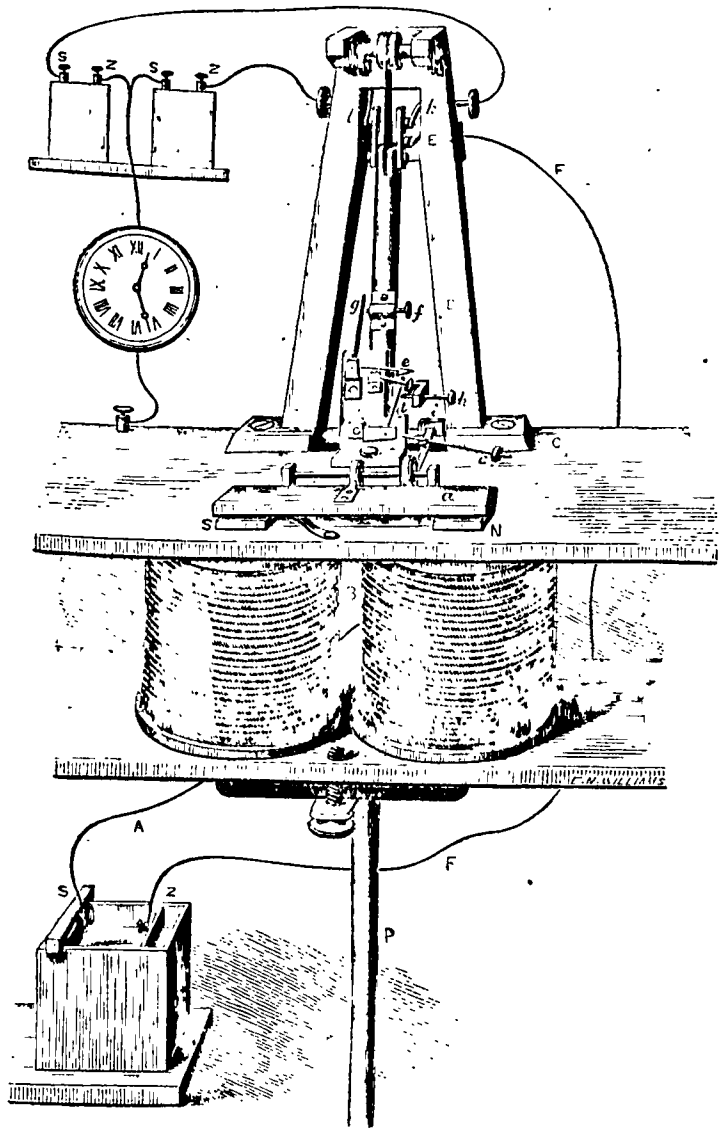

Fig. 410.

current circulates, the keeper *a* is attracted by the poles N S; as it descends, the lever *b* rises, and lifts up the wire that carries the small ball *c*; the wire *d*, attached at right angles to the other, moves to the left, and slides under and is caught by the detent *e*, and retained there until the detent is raised. Now when the pendulum is near the limit of its left-hand swing, the point of the screw *f* impinges against the flat face of the wire *g*, which forms part of the detent *e*, moves it slightly forward, and by this means raises the detent. The piece *c d*, being no longer under constraint, falls by the mere gravity of the ball *c*; and in falling the flat face of *d* strikes against the point of the screw *h*, which is fitted on the pendulum; and thus imparts an impulse to the pendulum sufficient to maintain its vibration. Meanwhile, the magnetism having ceased, the counterpoise *i* descends, and raises the keeper from the poles N S, ready to suffer a new attraction, and to repeat the process above described. The screws *f* and *h*, as well as the little ball *c*, are capable of adjustment so that the arc of the pendulum's vibration may be regulated.

Thus far in respect to the pendulum. The clock has two pairs of coils, with a continuous wire; and a pair of magnetized bars, attached to the same axis and oscillating see-saw fashion, according as the electro-magnetic poles beneath them are changed. The current for the clock is furnished by two distinct batteries, shown above, — one battery producing a current through the coils in one direction, say for the right-hand oscillation, the other producing a current in the other direction for the other oscillation. The silver end of one of these batteries is connected with the insulated spring *k*, and the zinc end of the other with the insulated spring *l*; the other ends of the respective batteries are connected together and led away to the beginning of the clock-coil; the end of the clock coil is connected with the bed or brass plate C, and consequently with the frame D and its suspended pendulum-rod. It is therefore evident that at each oscillation of the pendulum, whether to the right or left, the circuit of one of the batteries is completed, and this alternately; and, as the batteries are connected in reverse order, currents in alternate

directions will pass in succession through the clock-coils, and thus produce an oscillating motion of the magnetized bars. The axis on which the bars are fixed, is furnished with a pair of pallets, which work in a scape-wheel; and hence, by an ordinary train of wheels, communicate with the hands of the clock. Several clocks are placed in the same circuit; or the circuit is divided and some clocks placed in one division and some in the other, care being taken that the resistances are properly balanced, so as to insure a working quantity of current on each circuit. Sometimes contact springs are placed within the range of the oscillating bars of the clock; and, by means of the contacts thus made, distinct batteries are put into circuit for actuating distant clocks.

The one pendulum at Greenwich actuates a set of clocks, including a large public one exhibited at the gates; and also a large public one at the London terminus of the South-Eastern Railway, six miles distant from the pendulum, and with which it is in electrical connection by a wire passing under ground for two miles from London, thence along the telegraph poles to Lewisham, and thence under ground along Blackheath and through the Park to the observatory.

The prime clock at Greenwich is furnished with contact-springs and pins for transmitting the hourly time signals, and for other purposes. Shepherd's electric clocks are fitted up at the post-office, Lombard Street, London, the chief one of which raises a small weight in the course of the twenty-four hours; and the weight is dropped by a signal from the Greenwich clock, at a given hour daily, and in its fall sets the clock right, whether it may have been fast or slow: previous to which rectification, the post-office clock had sent a signal to Greenwich showing its error; and now, after the drop, it sends another signal which shows that the error has been corrected.

The special duty of the London terminus clock (besides that of showing true time) is to join the Greenwich and Deal wires together just before 1 P.M. daily, so as to secure the circuit for the ball-drop at the latter place; and other wires at other hours for time-signals. An analogous junction is

necessary at Ashford, and this is done also by an electric clock; which clock (having a small gaining rate) stops daily at 1 P.M., having made and holding on the contact; and is started by the Greenwich signal on its route to Deal.

Chronoscopes.

The name of chronoscopes has been given to instruments, which are employed for estimating the duration of very short intervals of time, and which have especially been applied to the measure of the velocity of projectiles. Mr. Wheatstone appears to be the first who has endeavoured to employ the properties of the electric current for this purpose; MM. Pouillet, Bréguet, Siemens, and Henry have been for a long time occupied on this subject.

Mr. Wheatstone's apparatus, by means of which the velocity of a bullet is measured, is composed of a clock movement, the progress of which is arrested by a catch of soft iron maintained in its position by the attraction of an electro-magnet. The circuit, through which the current passes that magnetizes it, is interrupted at the moment when the bullet comes out of the gun by the breaking of a wire that is stretched across; and it is re-established at the moment when this same bullet arrives against the target so arranged that the slightest motion that is imparted to it establishes a permanent contact between a spring and another metallic piece. The clock movement and the indicating hand that it carries then move on during the time, that elapses between the departure of the bullet and its arrival at the target, so that we have the measure of this time, and consequently that of the velocity of the projectile. The coercitive force of the soft iron, which prevents the electro-magnet ceasing to attract its armature from the moment when the current ceases to pass, was a very grave cause of error in this apparatus. Mr. Wheatstone has succeeded in causing it almost entirely to disappear.

The apparatus invented by M. Bréguet depends absolutely upon the same principle. It is a cylinder, actuated by a rotatory motion, upon which are applied styles along the same generating points of the cylinder, when they are no

longer retained by their respective electro-magnets. The bullet, in traversing screens placed at known distances, cuts successively the circuits of the currents that are passing in these electro-magnets. As the velocity of the rotation of the cylinder is known, we conclude from the angle through which it has turned between the marks of the two styles the time which the bullet has taken for traversing the distance of the two corresponding screens. The arrangement proposed by Mr. Siemens consists also in having a rotating cylinder; but it is the discharges of two Leyden jars, which are brought about by the projectile in two given points of its path, which produce by their sparks two spots upon the cylinder of polished steel.

Thus, in these applications to the determination of a very short interval of time, electricity serves merely as the medium between the projectile and the counting apparatus — a valuable medium; for we can conceive that it would be a difficult matter to realize a mechanical arrangement, in which the blow of the bullet could be transformed into a single pressure upon a train of wheels.

The chronoscope invented by M. Pouillet is founded upon an entirely different principle. His process consists in measuring the time during which a current circulates in a galvanometer by the amplitude of the deviation of the magnetized needle. In order to find the relation that exists between the duration of the electric current and its effect upon the galvanometer, M. Pouillet has employed a circular plate of glass, upon which is glued a slip of tin-foil, as a radius of a circle, communicating metallically with its axis. Suppose that a rapid rotatory motion is imparted to the plate, and that we place in communication with the two poles of a battery the axis of the apparatus and a spring that rests upon the circumference of the disc, the circuit will be closed only during the passage of the band of tin-foil under the spring. From the velocity of the rotation and the width of the band of tin-foil, we deduce the duration of the current, at the same time that we measure its effect upon a galvanometer. Thus it is that M.

Pouillet has been able to prove that a Melloni's galvanometer gives 15° of deviation, when a current of a single Daniell's element is made to act upon it, for $\frac{1}{1500}$ of a second; and that he has graduated this instrument, by causing both the duration as well as the intensity of the current to vary. M. Pouillet employed this process for measuring the time that a ball requires for coming out of a cannon or a musket. The two extremities of a circuit (*fig.* 411.), in

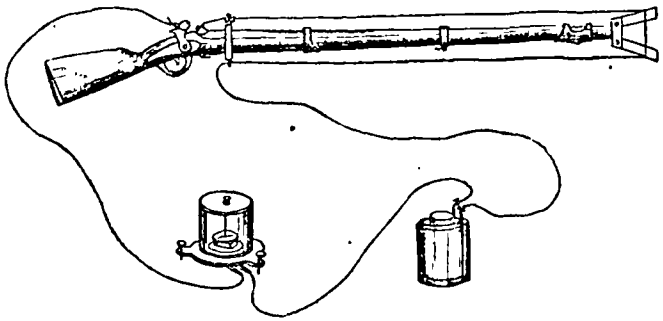

Fig. 411.

which are included the galvanometer and a Daniell's element, are adapted one to the cap put in its place on the nipple, the other to the hammer, the whole of the battery being well insulated from the gun; the wire passes before the mouth of the gun so as to be cut by the ball at the moment when it comes out. When it is fired off, the current passes during the time that elapses between the instant when the hammer touches the cap, and that in which the ball comes out of the gun. According to M. Pouillet's experiments, this time has always been found to be comprised between $\frac{1}{140}$ and $\frac{1}{150}$ of a second. We may conceive that merely an arrangement of screens, analogous to that of which we have spoken above, is required for the application of the same principle to the measuring of the velocity of a projectile in various points of its path.

Electric Bells.

We have seen that upon every telegraphic line, whatever be the system employed, there is always beside the receiver

an apparatus called the alarum, in which a hammer, striking upon a bell, is set into motion as soon as a current passes in the telegraphic circuit; and thus warns the person in charge that a despatch is about to be transmitted to him. These apparatus, for which various models have been proposed, nearly all consist of a clock movement, to which the armature of an electro-magnet serves as a stop, so that it only acts during the passage of the current. M. Mirand has successfully applied the principle of electric bells, as substitutes for ordinary bells in the service of houses, and especially of hotels. The apparatus that he employs is quite analogous to the interrupters*, in which an armature oscillates before the poles of a double electro-magnet during the whole of the time that a current is magnetizing it. Here the armature is connected with a hammer striking upon a bell, and this hammer, according as the current is made to pass for an instant only, or is allowed to circulate for a longer time, strikes one blow, or produces by the rapid succession of its percussions a sonorous rolling. In each of the rooms that are required to be placed in communication with the apparatus, there is fixed against the wall a disk of wood, in the middle of which is an ivory knob; on pressing upon this knob, the circuit, that passes through the sounding apparatus, is closed. By this arrangement, they are able not only to ring, as is done with an ordinary bell, but to give orders by employing certain conventionals for isolated blows and rollings to succeed each other.

Electric Weaving.

The application of electro-magnetism to weaving, discovered a few years ago by M. Bonelli, must justly be considered as a great and beautiful invention. Although the electric loom, at the point to which its inventor has brought it, cannot advantageously replace, in all its relations, the Jacquard system, it is not the less an evidently useful application of electricity, the characteristic properties of which here find their employment; and it is more than probable that progressive improvements in the arrangement and details of

* See Vol. I. p. 295.

the apparatus, will end by giving to it a marked superiority over the loom at present employed.

In order to study M. Bonelli's invention, it is indispensable first to give a general idea of the Jacquard loom, and of the manner in which it acts. We know that a woven fabric is composed of two series of threads, placed beside each other in two directions perpendicular to each other, and which interlace each other so as to give solidity to the stuff. In weaving, the threads of one of the systems are longitudinal, isolated from each other, and stretched parallel in a same horizontal plane. They constitute the *warp*. In *fig.* 412. they are the threads, *f f*, &c. The threads of the second system interlace transversely those of the former, and are formed by a single thread bent successively upon itself, as shown in the figure. They constitute the *woof;* and a single course of woof, equal to the width of the warp, is designated by the name of weft. The operation of weaving consists in raising a certain number of threads of the warp, and, between the threads raised and those which have remained on the horizontal plane, causing the thread of the woof to pass, conducted by a small apparatus, in the interior of which it is wound, and which is called a *shuttle*. When the shuttle has passed, the raised threads fall again, and one weft is woven. So long as only a plain fabric is required, the thread of the woof, requiring to pass regularly above and below the consecutive threads of the warp, as is represented in *fig.* 412., the operation is not difficult to realize; and we can easily conceive that all the threads of even numbers, being connected to a same rigid horizontal rod, whilst all the threads of uneven numbers are to another, the successive elevation of the two rods produces that of the two series of threads, between which the shuttle is to pass. But, for figured fabrics, upon which the patterns are obtained by the interlacing of threads previously coloured, the thread of the woof must, for each weft, allow certain of the threads of the warp to

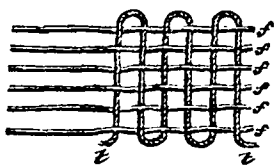

Fig. 412.

appear, which, by their position and colours, are related to the design that is desired to be traced. Hence, as we may comprehend, the raising of the threads of the warp can no longer be accomplished in a regular manner by even and uneven numbers; and each stroke of the shuttle must be preceded by a minute and complicated choice of the threads to be raised and lowered. This it is that constituted the art of knitting before Jacquard's beautiful invention.

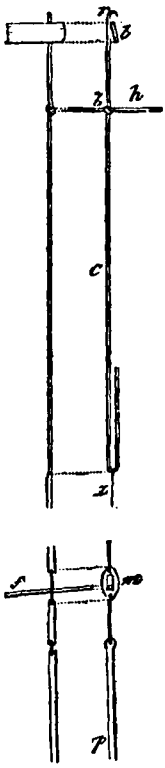

Fig. 413.

Figure 413. represents the arrangement given to each thread of the warp in the art of weaving, seen on two different sides. The horizontal thread *f* passes into a glass support, *m*, called a *loop*, to which is suspended a leaden cylinder, *p*; the loop is tied by a thread or *string*, L, to the vertical rod *c*, which passes without friction in the ring *b* of a horizontal rod *h*, and is terminated at its upper part by a very open hook, *r*; this hook rests upon a plate *l*, placed a little aslope, so that the least lateral motion given to the rod *c* is sufficient to liberate the hook from its point of support. *Fig.* 414. shows the arrangement of the vertical rods or *needles*, which are ranged in a certain number of vertical planes parallel to that of the figure: each of the horizontal rods *h* is retained on the right in a sheath, where it is supported against a spring. The following therefore is the mode by which it is brought about, that certain selected threads are raised at each weft, in order to allow the shuttle to pass and to produce the design in question. A wooden prism, R, actuated by a lateral motion from right to left, presents against the extremity of the horizontal rods its face pierced with holes, corresponding to these rods, but covered with a band of card, which, being itself pierced with a certain number of holes, leaves those open that correspond to them in the prism, and closes the others; the horizontal rods, before which the

openings of the prisms are closed, are repelled to the left, and each liberates its needle from the plate *l*, which was

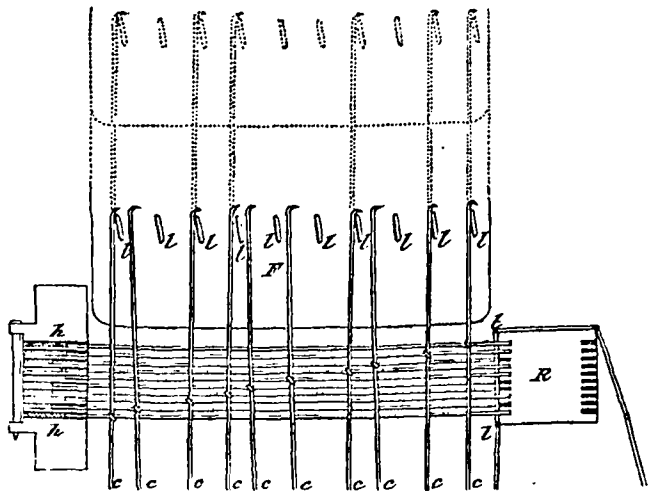

Fig. 414.

retained in its hook. At this moment these plates *l* rise with the frame F, to which they are fixed, and they raise only the needles whose horizontal rods have found holes in the card; the shuttle passes; the frame falls again. Then the same operation recommences; only the prism R has turned one quarter of the circumference, and it is a fresh card that presents itself, corresponding to the fresh weft. All these bands of card form a long warp conducted by the prism R, and one cylinder. We see that one is necessary for each transverse thread of the fabric, which causes certain designs to require as many as 100,000 of them. We can conceive how embarrassing such a warp must be to manage, whatever situation it may occupy, and the enormous price to which the setting up of the cards of a complicated design amounts, an operation which requires skilful workmen.

Instead of cards, M. Bonelli takes a metallic paper and traces upon it, with an insulating varnish, the design that he desires to reproduce upon the fabric. The following is the principle of his invention: — Suppose a number of electro-

magnets equal to that of the needle *c* of the Jacquard loom; and let us assume that, by any arrangement, the wire that surrounds each bobbin shall have one of its extremities always in contact with the pole of a battery, and the other with the card of which we have been speaking; the second pole of the battery communicates with the metallic surface of this same paper, which receives a motion of translation. By the effect of this motion, the wire of any electro-magnet will be in contact, sometimes with a metallic part, sometimes with a non-conducting part, according to the configuration of the design. In the former case, the current will pass into this electro-magnet; in the latter it will not pass. The only further question is, by a more or less ingenious mechanism, to place each electro-magnet in relation with a vertical needle, by employing the electro-magnetism developed in one case and not in the other, in order that the electro-magnet may raise the needle or leave it, according as the current passes or does not pass. Let us suppose a white warp with a black woof, and let us consider one of the threads of this warp. The thread will be covered by the woof, or will show itself according as the conductor, abutting on the electro-magnet which corresponds with it, may be in contact along the line that it traces upon the typed design with a surface of metal or one of varnish: the line, formed upon the fabric by this thread of the warp, reproduces, therefore, a change of colours, in passing from white to black, or from black to white, each passage from one of the surfaces to the other upon a line that corresponds with it in the typed design. Thus the pattern is reproduced; the proportions alone vary with the velocity of the motion that is imparted to the paper.

Fig. 415. indicates the arrangement that M. Bonelli had adopted in his first attempt. A vertical needle is supported upon the frame *a b*, by a little cylinder, *f*, of soft iron; *e* is the electro-magnet, corresponding with the needle. The wire, by which it is surrounded, has one of its extremities upon the metal rod *c d*, which supports a whole row of electro-magnets, and which is constantly in communication with one

of the poles of the battery, and the other is attached to the metal plate *l*. All these plates placed with knife edges on a support, *k*, and separated from each other by sheets of card,

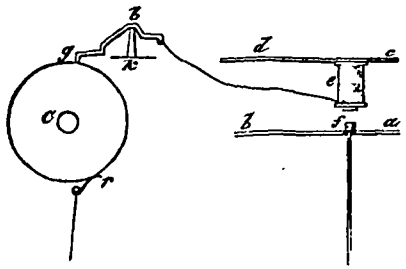

Fig. 415.

forming a sort of comb, the teeth, *g*, of which come into contact with the cylinder *c*, when the support falls. The cylinder is covered with the typed design, and a spring, *r*, puts the second pole of the battery into communication with the metallic surface of the paper. For each stroke of the shuttle, the frame *a b* raises the needles, and all the soft irons come into contact with their respective electro-magnets; at this moment the comb falls, and the cylinder, which is caused to revolve by mechanism one notch for each stroke of the shuttle, presents under the plates the transverse line of the pattern, which is transferred to the weft which is about to be woven. All the teeth that are in contact with the metallic part of the paper allow the current to pass; and, when the frame descends again, the needles corresponding to these plates remain suspended to their electro-magnets.

In this arrangement, the magnetic force of each electro-magnet should be sufficient for its being enabled to support the weight of the needle, and of the leaden cylinder suspended to each thread. It would therefore be necessary, on the one hand, to give to it relatively considerable dimensions, which would necessitate increasing the distance of the needle; and, on the other hand, to employ currents of a certain intensity, which, independently of the expense, would easily deteriorate the apparatus.

M. Bonelli was therefore led to adopt another arrangement, in which electro-magnetism plays exactly the part of the cards of the Jacquard loom. The electro-magnets have nothing beyond a lateral action upon the needles, liberating them, at a given moment, from the support which raises them. This was already a great advance, in this respect, that we must spare the electricity as much as possible all development of mechanical force, and employ its essential property, instantaneity, for changing, at a given moment, the relative arrangement of the pieces of a machine. In *fig.* 416., *h* is a

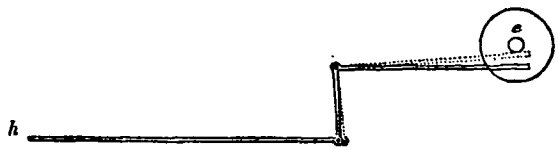

Fig. 416.

horizontal rod of the Jacquard loom (vide *fig.* 414.), seen from above downward; *e* is the corresponding electro-magnet; beside its pole is found the extremity in soft iron of a lever which, by a return motion, communicates with *h*. When the armature is attracted, the rod *h* receives a lateral movement from the left to the right, and it liberates from its support the needle that is connected with it, absolutely in the same manner as is done in the Jacquard loom, when it is repelled by the cards. M. Bonelli also modifies the nature of the paper, with which the cylinder is covered. Upon ordinary paper is traced with varnish the design that is to be reproduced; it is then covered with a thin sheet of tin foil, with which it is left in contact for a short time; on then rubbing the paper with a tuft of cotton, the tin remains adhering to the varnish, and disappears where there is none.

In this manner the loom which was exhibited by M. Bonelli in Paris acted. We shall not enter into all the details of the apparatus, which would lead us on too far: besides, M. Bonelli himself perceived that there were still a great number of difficulties to be overcome.

M. Froment is at present occupied with the modifications,

that M. Bonelli's apparatus must be made to undergo. In that which he proposes to construct, the magnetic action will take place in the direction of the axis of the electro-magnet, which will be horizontal and not lateral (vide *fig.* 416.). M. Bonelli had been prevented adopting this arrangement, from the impossibility of giving to his electro-magnets a sufficiently small diameter for their being each opposite to their corresponding rods; but M. Froment overcomes the difficulty, by further diminishing the magnetic force that each electro-magnet will develope. *Fig.* 417. indicates the

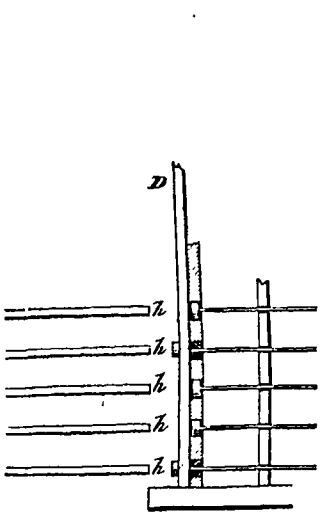

Fig. 418.

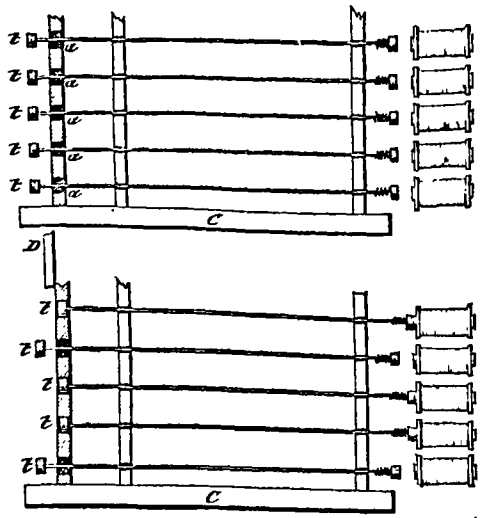

Fig. 417.

principle of the arrangement that he purposes adopting. Before each electro-magnet is situated a horizontal rod, terminated by a piece of soft iron, and at *t* by a little copper cylinder or head. All these rods are able to move laterally in the frame C, by which they are supported; and this frame is itself capable of acquiring a movement of translation. For each stroke of the woof, it advances first from the left to the right, and applies all the soft irons against the poles of their respective electro-magnets; it then starts again in the opposite direction, and draws with it only the rods that are

applied against the inactive electro-magnets. When the frame is sufficiently distant from the heads, *t*, of the rods that had remained adhering, to have passed into the openings *a*, the current ceases everywhere; and the frame continues to advance, carrying with it all the rods into the respective positions which they have taken. At this moment a shutter, D, falls and closes the openings before the heads of the rods that have remained in the frame, at the same time that it serves as a support to those which are without (*fig.* 418.). Then it is that the side of the frame which is still advancing meets the extremities of the horizontal rods, *h*, of the loom, and acts upon them as the Jacquard card, by thrusting laterally those which correspond to the heads, *t*, that remain out of the frame. Thus the electro-magnetism will have to overcome nothing beyond the feeble resistance of the small rods upon their slides; and M. Froment, while still giving to his electro-magnets a power of action very superior to that which is necessary for them, is able to render their dimensions sufficiently small for placing each of them opposite to the corresponding horizontal rod. The improvements will also bear upon the mode of communication of the wires with the metallic paper; besides, a commutator will close the circuit an instant after the contact of the teeth with the typed design and will break it an instant before this contact ceases. This arrangement will cause the induction sparks to disappear, which would end by deteriorating the paper.

In the description that we have been giving of M. Bonelli's invention, there are a certain number of details, referring especially to the art of weaving, into which we have been unable to enter. It seems to us that, logically, we ought to see in these difficulties nothing which the electric loom may be unable to surmount, as the Jacquard loom has done; since, in fine, a card is only susceptible of presenting full parts and hollow parts, as this paper, which is substituted for it, presents conducting parts and others that are not so.

Apparatus for maintaining the Motion of the Foucault Pendulum.

In the beautiful experiment devised by M. Foucault, in which the invariability of the plane of oscillation of a pendulum gives the demonstration of the rotation of the earth, the amplitude of the movements of the pendulum gradually diminishes on account of the resistance of the air. M. Foucault has found out a very ingenious method of preserving this amplitude indefinitely, without influencing in any way the direction of the plane of oscillation, by employing the attraction exercised by an electro-magnet upon the sphere, which moves under the action of gravity. This application of electro-magnetism has this remarkable feature in it, that it presents the first example of a commutator acting without there being any contact between the fixed part of the apparatus and that which is in motion.

Fig. 419. represents the arrangement adopted by M. Foucault according to a drawing which he has been good enough to communicate to us,

An electro-magnet, E, placed exactly in the vertical of the point of suspension of the pendulum, rests upon a spring, R, supported by the plate A B. A vertical rod fixed to the electro-magnet passes through the spring, and terminates by a hook, *o*, into which is fitted the lever *a p*, kept in equilibrium by the weight *p*, and carrying a contact piece, *a*, which is able to touch the piece *b*, the height of which a screw serves to regulate A bent lever, which tends to raise the spring R′, carries an armature, *e*, placed above a second electro-magnet, E′, smaller than E, and arranged upon the same vertical; *c* and *d* constitute a similar contact to that of the first lever. The rod *e c* is terminated by a camm, which rests upon the teeth of a wheel, *r*, which is in gear with the pinion of a second wheel, *r′*, which communicates its motion to a small fan, *v*. From each of the poles of the battery come out two wires, so as to form two complete and independent circuits, one of which creates the upper electro-magnet, and the other the lower.

The sphere S, which moves under the action of gravity, is of copper, and contains a cylinder of soft iron, the axis of which is the prolongation of the suspension wire.

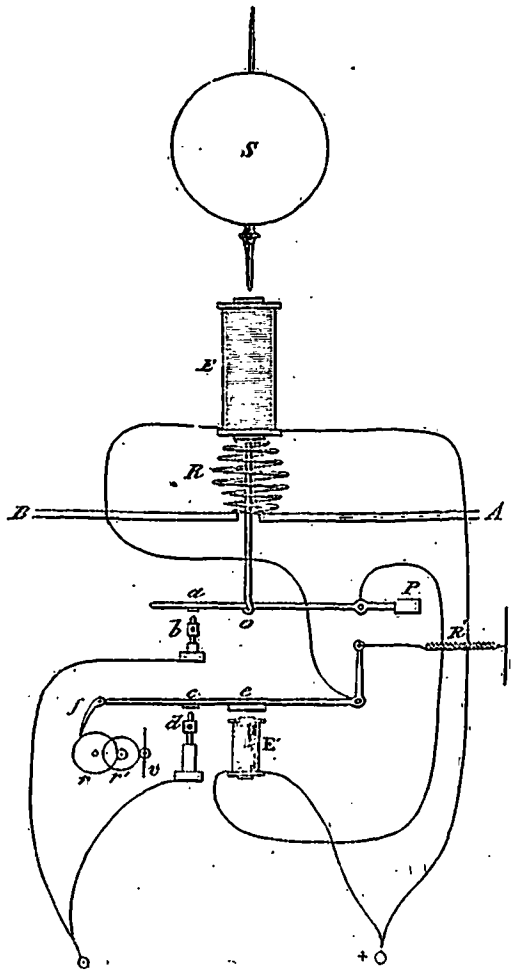

Fig. 419.

Suppose the pendulum at the extremity of its course: the spring R, slightly compressed by the weight of the electro-magnet, allows the contact *a b* to be established; from this it follows that the current passes to E', that the armature *e* is

attracted, the contact *c d* established, and that consequently the current circulates in E. When the wire of the pendulum arrives near to the vertical, the cylinder of soft iron placed in the interior of the sphere, being situated in proximity to the electro-magnet, is attracted, and the pendulum receives the impulse which preserves the amplitude of its oscillations. We should remark that this impulse is always given to it in the plane in which it is moving, since this plane always passes through the vertical of the point of suspension, in which is also situated the centre of action of the electro-magnet E, and that of the electro-magnet E′, the attractive force of which, if it may not be neglected, is thus at least without influence upon the direction of the plane of oscillation. The following now is the mode in which the magnetization ceases from the moment in which the pendulum has passed beyond the vertical, and in which, consequently, the magnetic attraction would be opposed to its motion. The figure represents the apparatus at the moment in which the sphere is situated above E; the latter, which a very feeble effort is sufficient to raise, on account of the elasticity of the spring, is attracted vertically by the soft iron, rises through a small fraction of an inch, and raises the lever *a p*, which interrupts the contact *a b*; the electro-magnet E′, ceasing to be magnetized, the spring R′ raises the bent lever, the contact *c d* is interrupted, and the current is no longer able to circulate to the electro-magnet E. But it was of importance to arrange things in such a manner that the current could not be re-established in E before the sphere was beyond its magnetic field. Now, as soon as the pendulum has passed beyond the vertical, the electro-magnet falls again, and E′ being magnetized anew attracts its armature; but the camm *f*, arrested by the teeth of the wheel *r*, permits the lever to descend only by a slow and regular motion, which is regulated by the fan *v*, so that the contact *c d* is not re-established until at the end of a certain time, when the sphere of the pendulum is beyond the magnetic field of the electro-magnet.

Electro-Sorting Apparatus.

In the metallurgy of iron, as it is generally practised, the separation of the metal and the matters which accompany it, or *slag*, takes place by means of fusion; the more dense cast iron runs out below the dross, by which it is covered. Another process, put forth by M. Chenot, consists in first separating in a solid state the iron, or rather the oxide of iron, from its slag, then in reducing this separated mineral, by employing a temperature very much lower than that which produces the fusion of cast iron. By his method M. Chenot obtains the iron in a state of metallic sponge, which enjoys the singular property of burning like charcoal, and which by powerful compression is transformed into ordinary iron. M. Chenot employs the iron obtained in this particular state in a new and interesting fabrication of steel, which consists in producing the cementation of the iron, by placing the metallic sponge in contact with a liquid compound of carbon, — tar, for example, which penetrates into the whole of its mass, producing by a sudden elevation of temperature the combination of the two elements. We here point out the principle of this metallurgic method, in order to make the application to it that is found in electro-magnetism comprehensible. In fact, the mineral is separated from its slag by making use of its magnetic properties, that are developed, if its iron is in a state of peroxide, by placing it in contact with the vapour of water, which causes it to pass into the state of magnetic oxide.

We are indebted to M. Froment for an electro-sorting apparatus which, by its proportions, the rapidity with which it acts, and the quantity of material upon which it is able to operate, assumes the rank of an industrial machine. It is represented in profile in *fig.* 420. A circle of cast iron, the diameter of which is about one yard, revolving upon a horizontal axis, perpendicular to the plane of the figure, carries at its circumference eighteen electro-magnets, the axes of which are placed in the direction of the prolongation of the radii of the circle. Below, an endless web passes over

the cylinder *c*, and over a second cylinder exactly similar, placed behind the former, so that the upper surface of this

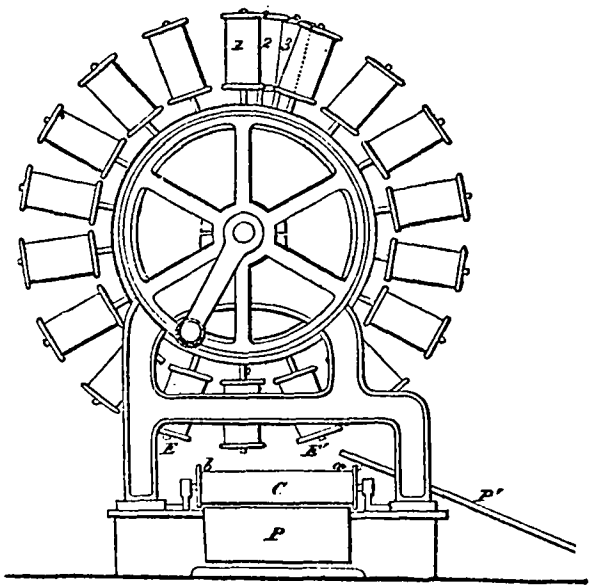

Fig. 420.

web, the projection of which is *a b*, moves in a horizontal plane, perpendicularly to that of the figure, when the cylinders which guide it receive a rotatory motion. The iron ore reduced and pulverized is spread continually upon one of the extremities of the cloth; drawn along with it, it passes under the electro-magnets in motion.

A commutator, which is not represented in the figure, is so arranged as to allow the current of the battery that is in action to pass only into the bobbins that occupy for any instant the lowest arc of the circumference, so that each soft iron, on arriving at E is magnetized, remains magnetized from E to E′, then loses anew its magnetic properties. By this arrangement, and by the combined motions of the wheel and of the cloth, all the iron that is contained in the ore, is attracted in proportion as it arrives, remains adhering to the soft iron, which has raised it, and does not fall off until the latter is demagnetised, so that it is received upon the inclined

plane P′, and is thus found to be separated from the matters, both metallic as well as earthy, with which it was mixed; these latter, continually drawn on by the movement of the cloth, are diverted upon the inclined plane shown at P.

Instead of a second row of electro-magnets, as we have supposed in the figure, there are three in M. Froment's electro-sorting machine. Let us conceive three circles, furnished with electro-magnets, exactly similar to that which we have described, placed one behind the other upon the same axis, but not entirely in the same position, so that the axes of the bobbins of the second and of the third are separated by equal distances, in the angular interval which the axes of the two bobbins consecutive to the first leave between them,—an arrangement represented in dotted lines for the electro-magnets, marked with the numbers 1, 2, and 3. The commutator acts at the same time for the three rows of bobbins. By this arrangement there is no part of the ore that can escape the magnetic action, and the operation takes place, so to speak, in a continuous manner.

The soft irons have not a cylindrical form; their section is very elongated perpendicularly to the plane of the figure; that is to say, in the direction according to which the ore is advancing. Motion is communicated to the apparatus, either by the aid of a handle, or by means of an endless band passing over the drum of a steam-engine, and upon a cast-iron pulley which, in the figure, conceals in part the circle to which the electro-magnets are fitted. We have not represented the mechanism by which this motion is transmitted to the cylinders carrying the endless cloth, the velocity of the rotation of which must be regulated according to the richness of the ore in iron, and which gives a backward and forward motion to the funnel which contains the pulverized material, so as to distribute it in a regular and continuous manner upon the movable cloth.

Application of Electro-magnetism to the adhesion of Locomotives upon the Rails, to the transmission of Motion, and to applying the Breaks of Trains.

We know that a railroad should present no gradient but such as is scarcely sensible; and that, should the inclination of the rails exceed a limit insufficient in the majority of cases for avoiding heavy works, the wheels of the locomotives would slip, that is to say, would revolve upon themselves without advancing; because the friction developed at the points of contact of the wheels and the rails might not any longer be in equilibrium with the resistances of the train. By increasing the weight of the locomotive, we increase, it is true, the value limit of the friction, which is proportional to the normal pressure; but the resistance also becomes greater; and the difficulty consists precisely in separating these two elements from each other, namely, in discovering the means of increasing merely the normal pressure in the direction of the rails. An electro-magnetic attraction naturally presented itself, as the solution of the problem; and this idea was put forth particularly by M. Weber and M. Liebig. M. Nicklès is the first who seriously occupied himself in this question; and, although his works upon this subject have not yet led to any practical results, we are at least indebted to him for some useful trials and some accurate data.*

A very simple process consisted in connecting with the locomotive some electro-magnets, which were as near as possible to the rails, so as to act upon them with great power. Experiments made on the small scale succeeded very well; but no practical result could be hoped for, on account of the enormous magnetic power which it would have been necessary to obtain for this purpose. M. Nicklès then conceived the idea of magnetizing the driving wheels, by enveloping each of them near its point of contact with the rail with a helix, the inner surface of which embraces the felloe

* Thesis of Physics presented by M. Nicklès to the Faculty of Sciences of Paris. *Archives des Sciences Physiques et Naturelles.*

without touching it.

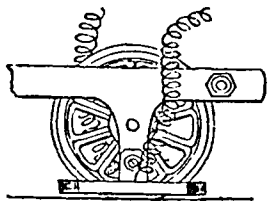

Fig. 421.

Fig. 421. represents the wheel of a trial apparatus, which acts successfully; and it is as the result of these first experiments that M. Nicklès made the application of his process to a locomotive that was placed at his disposal upon the Lyons railway. The battery, composed of 64 Bunsen's elements, was placed in the tender; and each of the two helices, which surrounded the lower part of the driving wheels, was composed of a wire 1700 feet in length, forming 216 convolutions, and $\frac{1}{6}$ in. in diameter. The weight of the locomotive was 29 tons, that of the entire train 119 tons. The trial was made upon a gradient of 1 in 100; and he was able to prove that the magnetization of the wheels produced an increase of adherence of about eight per cent. when the locomotive was travelling at a small velocity. These experiments showed also that the electro-magnetic adhesion decreases very rapidly when the velocity increases; which is due, according to M. Nicklès, to the two following causes: —

1st. The displacement of the magnetic pole; which, when the wheel is at rest, is situated at its point of contact with the rails, but which is displaced during the motion, and is transported backwards.

2nd. The coercitive force of the cast iron of which the wheel is composed, which diminishes the intensity of the magnetism; because any one portion of the felloe passes continually and with more or less rapidity from one polarity to the other. Finally, as M. Nicklès himself observes, we can approximate to his process by utilising only one of the two magnetic poles, developed in each wheel.

These considerations have led M. Nicklès to abandon the mode of magnetization that he had at first adopted, and to substitute for it that which he calls circular magnets. A bar of soft iron, enveloped by a helix, in the interior of which it is able to rotate, and terminated at its two extremities by discs also of soft iron, at the circumference of which this

magnetism possesses its maximum of intensity, constitutes a circular electro-magnet. (*fig.* 422.) According to the experiments of M. Nicklès, the best mode of turning to useful account the magnetizing power of a current is to produce in the middle of the electro-magnet a consequent point, by changing the direction there of the helix, and fixing there a circle of soft iron, similar to the other two. This arrangement is realized in the apparatus *fig.* 423., in which the electro-magnetic adhesion serves for

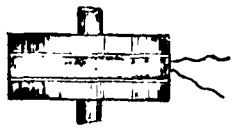

Fig. 422.

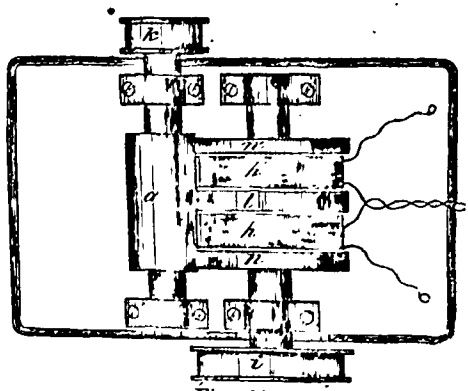

Fig. 423.

transmitting the motion of the pulley *i* to the pulley *k*. The helices *h* and *h'* are wound in directions contrary to each other, so that *n* and *n'* are north poles, and *l* a south pole; *a* is a soft iron cylinder against which the three polar circles of the circular electro-magnet adhere. We can conceive that, under this arrangement, the motion should not in any way change the conditions of the magnetism; and, setting out from data which have been furnished to him by apparatus analogous to that which we have been describing, M. Nicklès thinks that a driving wheel of a locomotive will be able, under conditions of magnetization easy of realization, to present an attraction of $2\frac{1}{2}$ tons per line of circumference. Now, in the experiments quoted above, 550 lbs. of attraction per wheel have furnished an increase of adhesion of 8 per cent.; therefore, by applying to locomotives the process of

circular electro-magnets, we should arrive at an increase of adherence of 91 per cent; and this adhesion would be sensibly constant for all velocities.

We may here say a few words upon another application of electro-magnetism to rail-roads, which, by causing a current to pass along a train, permits of all the breaks being put into action, as soon as the engine-driver desires to stop the train. M. Achard's *electric break* is the most satisfactory of all the apparatus that have been invented with this object in view. The break-gear is set in motion by the act itself of the travelling of the train, from the moment when a toothed wheel that is carried upon its arbor is thrust aside by a catch. Now, this catch becomes free to act only when a piece of soft iron, which is held in position, is attracted by an electro-magnet. Thus, from the moment when the driver closes the circuit that passes through all the electro-magnets, the break-gears commence acting; and, at the end of a few moments, stop the progress of the train.

Electric Registers.

We have already pointed out, in the Section on electric telegraphs, the service that had been derived from this mode of communication, for different scientific, and more particularly astronomic observations; we have likewise described, in the present Section, many important instruments and apparatus, founded upon the same principles. It remains for us to add a few details upon the application that has been made of it to the registration of certain observations.

Wheatstone, whom we always encounter when questions of this kind are in agitation, had devised a system of apparatus capable of being raised into the atmosphere by means of a captive balloon, which could give at different heights the temperature, the pressure of the air, the moisture, the intensity and direction of the wind, &c. The following is the mode in which he constructed the thermometer: — The motion of a small clock caused a vertical movement to descend and rise regularly in six minutes; this movement carries a fine

platinum wire, which moves in the thermometer tube, and the excursions of which have an extent, that corresponds to a greater or less number of the divisions of the thermometric scale. Two fine copper wires, covered with silk, and of sufficient length to connect the balloon with the earth in its greatest elevation, are fixed to the instrument in such a manner that the end of one of them plunges into the mercury of the thermometer, and the end of the other is in contact with the clock-wheels, which communicate metallically with the platinum wire. The lower ends of the two wires that reach the ground are united by a galvanometer and a very small battery of a single pair. The galvanometer remains at 0° so long as the platinum wire is not in contact with the mercury of the tube; but the needle deviates immediately that contact takes place, and remains deflected until the contact is broken anew by the ascent of the movement, which carries the wire. The time employed by the platinum wire to traverse the scale from top to bottom being three minutes, the wire traverses the 360th part of this scale during the half second of time, corresponding to the beats of the clock; and consequently each point of the scale corresponds to a different beat or to a different half second, taken in the series of three minutes. Hence, if an observer on the ground furnished with a chronometer, regulated so as to follow in its indications, the clock carried into space by the balloon, notes the precise instant in which the needle of the galvanometer has been deviated, he will deduce immediately, from this observation, the temperature indicated by the thermometer of the balloon; for, according to the different degrees of height at which the column of mercury may be, the contact of the platinum wire with the mercury, and consequently the current, will be established at one certain half second or at another. If the indications of the two chronometers did not correspond at the end of a series of observations, the results nevertheless would not be defective; it would suffice to subject them to a correction that is easily found.

We can add to the apparatus a thermometer with a bulb always moistened, a psychrometer, a barometer, an anemo-

meter, &c., an addition which simply requires that the movement be furnished with several platinum wires, and that the same number of silk-covered copper wires shall descend from the balloon so as to reach the earth and there serve to form a circuit, of which, as in the preceding case, a galvanometer and a voltaic pair must form a part.

The indications of the meteorological instruments may be transmitted to a distance by the action of an electro-magnet which causes a bell to sound or which prints a character; but when experiments to be made with captive balloons are in question, it is better to employ the deviations of a galvanometer, because they do not require so strong a current; and much finer and consequently much less heavy conducting wires may be employed.

To recapitulate: By means of the process devised by Mr. Wheatstone, we are able, every six minutes, to observe all the variations of pressure, temperature, humidity, &c., which are produced at a great height in space. We might likewise, by this method, determine at each instant the temperature and volume of the waters of even the deepest Artesian well.

Likewise, by causing the revolution, by means of a well regulated clock, of a cylinder covered with paper, upon which a style moved by an electro-magnet, whose magnetism is determined by the pendulum of the sidereal clock, imprints equidistant dots, Mr. Airy has succeeded in registering in a very convenient and precise manner the observations made with the transit instrument, as we have already remarked at the end of the preceding Section. In fact, if the pendulum of the sidereal clock beats seconds, the intervals comprised between the successive marks of the style correspond to a second of time; and when, at the moment of the passage of a star before the wire of the telescope, the finger is pressed upon the key of a commutator, the circuit of another current is closed, the motion of a second style is produced, which prints upon the paper of the cylinder a dot, the place of which is easily determined in respect to the equidistant dots marked by the first style. This interval is translated into

time; and the desired result is thus obtained with great precision, and in a very convenient manner. Mr. Airy has likewise employed the magnetic properties of the electric current, as we have already described, to cause a set of clocks in various parts of the Royal Observatory to go in a perfectly uniform manner, by employing arrangements which we have also fully described.

We shall not terminate this Section without making mention also of the happy application, which M. Palmieri has made, of the properties of electro-magnets to the construction of an apparatus intended for registering the shocks of an earthquake, and which he has designated under the name of *Electro-magnetic Seismograph.* This kind of apparatus is not new; since, for some years past, several philosophers, in particular Mr. Mallett in England, have been occupied in seeking for the means of obtaining the result that has been the object in view to M. Palmieri. It is, in general, by means of the displacement of a certain mass of mercury rendered appreciable, that we have succeeded in ascertaining the tremblings of the earth, and of appreciating, as much as possible, their intensity and direction. M. Palmieri has been led to direct his attention to this subject from the frequency of the shocks of small earthquakes that he has been able to observe at the Royal Observatory of Vesuvius. These local tremblings, which are sometimes felt as far as the neighbouring villages, are distinguished from those which shake extensive regions, and whose centre is situated elsewhere, in that they are small and of short duration, and that their force diminishes rapidly with their distance from the volcano in which they take their rise. Many of these shocks pass unperceived; and yet there is great interest in registering them accurately, indicating the precise time at which they commence; but among the known seismometers M. Palmieri has been unable to find any one that answered perfectly the object he had in view; that is to say, which should register of itself the smallest shocks, indicating the moment at which they take place, and making known whether they are vertical, or undulatory, or horizontal.

The new apparatus answers this purpose well; it is composed mainly of two distinct pieces of apparatus, one for vertical earthquakes, the other for undulatory or horizontal.

In order to form an accurate idea of the former apparatus, the one intended for vertical tremblings of the earth, it is necessary to conceive a helix of brass, suspended at the extremity of a spring, and carrying at its lower part a cone of copper or of platinum, situated at a very short distance above a surface of mercury, placed in a small iron basin; it is evident that, if a vertical trembling of the earth takes place, the extremity of the metal cone will arrive into contact with the mercury, by the effect of the elasticity of the spring and the helix. If, on the other hand, the helix and the mercury are reciprocally in communication with the two poles of a voltaic battery, the currents will be capable of transmission at the moment when the trembling of the earth commences. By introducing into the circuit an electro-magnet whose armature is fixed to an arm of a lever, we can conceive that we may be able at the same instant to stop a clock, forming part of the apparatus, and indicating the day of the month, the hour, the minute, and the second, and also cause a bell to sound. Besides the advantage of giving warning, the addition of the bell presents this convenience also, — that if the clock were stopped by some accidental cause, without the bell having been set in motion, the stopping of the clock could not be attributed to a trembling of the earth. Instead of employing a clock movement that stops, we could have made use of one at rest, which the trembling of the earth would have set in motion. M. Palmieri considers the former means preferable, when the object in view is to indicate the commencement of the trembling of the earth; he thinks of employing the latter for obtaining the indication of the return in a contrary direction.

The second apparatus, the one intended for registering the undulatory tremblings of the earth, is composed of four glass tubes, bent into the form of U, and containing mercury; one of them is directed from the South to the North, another from the East to the West; the other two have intermediate

directions. It is evident that an undulatory shock will cause the mercury to oscillate in one or two of these tubes; consequently, if we have plunged into one of the branches of each of the four tubes an iron wire, and in the other we have arranged a platinum wire, which is at a very small distance from the surface of the mercury, without touching it, the mercury, in oscillating at the moment of the shock, will come into contact with the platinum, and an electric current, finding its circuit closed, will stop a clock, and will cause a bell to sound. We are also able, by the stopping of the clock, to recognise that the trembling of the earth was undulatory, and to determine at the same time what was the approximate direction of the oscillation; in fact, each tube carries a mechanism similar to that of the wheel-barometer, with the sole difference, that the counterpoise being a little heavier than the float, the index, when once displaced, does not return to the zero of graduation. The displacement of the index, therefore, indicates which one or more of the four tubes may have experienced an oscillatory movement; and, as this displacement is permanent, their amplitude enables us, up to a certain point, to measure that of the oscillation. We can render the distance between the surface of the mercury and the extremities of the helix and platinum wires very small, provided we have a system of compensation which enables the distance to be constant, notwithstanding the variations of temperature. In this manner the apparatus acquires great sensibility, and is able to indicate the slightest shocks.

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CHAPTER II.

CHEMICAL APPLICATIONS.

General Considerations upon Electro-chemical Forces and their Applications.

We have set forth, in the Third Chapter of the Fifth Part of this Treatise, the intimate relations that exist between electric and chemical forces. We have insisted, especially in the theory of the voltaic pair, upon the manner in which the exercise of affinity may be facilitated by arrangements which permit of the circulation of the electricity with which it is always attended. We have likewise studied in detail, in the Third Chapter of the Fourth Part, the decomposing power of dynamic electricity, and the manner of opposing it to the force of affinity. It is easy to conceive, according to this double examination, the importance of the part that may be played by the judicious employment of electricity in the chemical arts, all of which are founded upon the effect and the conflict of affinities. Even very long before the connection that exists between electric and chemical actions had been discovered, electricity itself had without doubt been made to concur in the production of certain effects; for example, in the tinning of pins. It had been rightly suspected, shortly after the discovery of voltaic actions, that electricity plays a part in certain phenomena hitherto attributed exclusively to chemical affinity; such as the precipitation of metals from their solution, by the immersion of another metal into the solution: for example, by the immersion in a solution of sulphate of copper of a plate of iron, which is promptly covered by metallic copper. But none but confused ideas were entertained upon this subject,

on account of the absence of just notions of the relations by which the two kinds of force are connected.

Grotthus was the first who, in his work upon the influence of galvanic electricity upon metallic vegetations, had well conceived the part played by this electricity in these phenomena; he had, in fact, remarked that, when the metallic vegetation has commenced, the metal in solution is unable to continue to deposit itself upon the extremities of the vegetation, except so long as the latter communicates by one of its points with the metal, that serves as a precipitant, which forms a veritable voltaic pair. He had likewise observed that two metals, incapable, separately, of bringing about the precipitation of a metal held in solution, are able to produce it when they are placed in contact so as to constitute a voltaic pair. The following is a beautiful experiment of Grotthus's, in support of his conclusions. After having filled to half its height a tube $6\frac{1}{4}$ inches in height, and a third of an inch in diameter, with a concentrated solution of nitrate of copper, he poured gently upon it a pure and perfectly neutral solution of nitrate of silver, slightly alcoholic, and consequently not very dense, so that the two liquids were perfectly in contact, without, however, being mixed. A small cylinder of copper was plunged into the nitrate of silver, without being in contact with the solution of copper, which it does not precipitate; it does not fail to precipitate the silver, under the form of very fine garlands, in silver chains, finishing by approaching gradually to the blue solution of copper; and when they had attained to it, they were soon covered with particles of copper, the colour of which was perfectly distinct, and did not permit of being confounded with that of the silver. By substituting a zinc cylinder for that of copper, the precipitation of the copper, at the extremities of the branches of the silver, is much more prompt; it is true that the zinc would precipitate the copper from the nitrate of copper, if it plunged into it directly.

Bucholz was the first to show that the metals may form with their own solutions and water, whether pure or acid or saline, electric circuits, the action of which precipitates the

metal; thus, for example, on placing in a test tube a metallic solution of copper, as neutral as possible, such as sulphate of copper, and pouring upon it with caution pure or acidulated water, so that the liquids remain separated; if we then plunge slowly into the test tube a plate of copper, some hours after, the end of the plate that is in contact with the metallic solution is covered with a precipitate of copper. The electro-chemical effect arises from the chemical reaction of the water upon the part of the metal that is plunged into it,—a reaction which gives rise to a current, toward the production of which the chemical reaction of the two liquids upon each other also contributes. But this kind of action is less general than Bucholz had supposed; for there are metals, such as zinc, iron, and tin, which with a solution of their respective sulphates and waters present contrary electric effects, the solutions attracting more strongly the metal than the water attracts them; so that the metal is deposited upon the end that is plunged into the water. Thus, when a concentrated solution of proto-chloride of tin is employed, placed at the bottom of the test tube, and the upper liquid is water or a very diluted solution of the proto-chloride, the plate of tin, plunging at the same time under the two liquid beds, the metallic deposit is brought about, under the form of radiating needles, upon the upper part of the plate; this deposit commences at the surface of separation of the two liquid beds; and, at the end of several days, there is an abundant metallic deposit. We are able to obtain a similar effect even with copper; and, consequently, a contrary effect to that which is ordinarily obtained; for this purpose, we have merely to plunge a plate of copper into a test tube, the lower liquid of which is acid proto-chloride of copper, and the upper liquid ordinary water, which attacks copper less than the acid proto-chloride. M. Becquerel, for the purpose of obtaining either revivified metals or metallic compounds (oxide and salts of different kinds), has frequently employed apparatus founded upon the principle of Bucholz' experiments.

The most complete work that has been done upon the reduction of metals by the humid way, is, incontestably, that

of Fischer of Breslau. Although this chemist, in these phenomena, had seen only the simple effects of chemical affinity, and had too much neglected the influence over their production of the electric forces set into play, yet the very considerable number of well-observed facts, which he has described, gives a great value to his researches; which, on being studied closely, may usefully contribute to establish the relations existing between affinity and electricity. The experiments were made by giving to the reducing metals the form of wires, rods, or plates, except for some, such as cobalt, uranium, and manganese, which he had been compelled to employ in the state of buttons or globules; in general, the operations were carried on in open vessels, and in such a manner that the upper part of the reducing metal could come out of the liquid, except in certain cases, in which the reducing metal was plunged entire into the liquid, and the vessel hermetically closed.

The experiments have been directed to eighteen different metals; each has been tried successively as a reducer in the solution of various salts, formed by the others; and this has led to their being grouped into four classes or series, namely: 1st, Reducible metals; 2nd, reducing metals; 3rd, (non-reducible metals) metals which cannot be reduced; 4th, (non-reducing metals) metals which cannot reduce.

If the reducible metals are classed according to the force and the facility with which they are reduced, we find the following order: gold, silver, osmium, palladium, iridium, platinum, rhodium, mercury, tellurium, copper, antimony, bismuth, arsenic, lead, tin, nickel, cadmium, and iron. This order is a little different if we group them, following an order relative to the numbers of the metals by which each of them is reduced; in such sort, that the metal reduced by the greatest number of other metals is at the head, and the metal reduced by the least number, at the foot of the series. Thus, in this second series, silver must be placed after the metals from platinum, whilst it is placed before in the former series; it is the same for copper, in respect to antimony, bismuth, and arsenic.

The reducing metals, classed according to the number of metals which they reduce, are found to occupy the following order: — zinc, cadmium, iron, tin, lead, cobalt, bismuth, copper, manganese, arsenic, antimony, nickel, uranium, mercury, tellurium, silver, palladium; lead and tin must occupy the same place, for they reduce the same number of metals, and reduce each other.

The irreducible metals are those which form acids, except arsenic; as well as uranium, cobalt, manganese, and zinc. The non-reducible metals are likewise those which form acids, except also arsenic, as well as gold, platinum, osmium, iridium, and rhodium. Finally, the only metals that are reducible by non-metallic substances, are gold, silver, osmium, platinum, palladium, tellurium, mercury, and copper. Among the non-metallic substances, phosphorus is the one that reduces the greatest number of metals.

Fischer, as we have said, attributes the greater number of facts of the class of which we have just been speaking, to simple chemical affinity, without the intervention of electric forces; in support of his opinion, he quotes several remarkable observations; however, it appears evident to us that, if chemical affinity is the first cause of the precipitation of one metal upon another, the electric current which accompanies this precipitation tends in its turn to increase it, and consequently concurs in its production. It is evident that in the case in which the body that determines the precipitation, such as phosphorus, is not a conductor, the effect is due only to the simple action of affinity; but also in this case it is much more limited. We may, moreover, remark that all the phenomena in question are a natural consequence of the manner in which we have regarded the production of voltaic electricity, and of the theory that we have given of that which takes place in a pair. Only here it is necessary that positive substance may be capable of decomposing by itself the metallic solution in which it is plunged; whilst in a pair, its action is facilitated by its contact with the negative substance; but when once decomposition has commenced, the deposit of a portion, however small it may be, of the revivified metal, is sufficient for producing this pair, and accelerates

the decomposition. We may also remark that it frequently happens that there is a pair without its being suspected. Thus, when a piece of common iron is plunged into a solution of sulphate of copper, the heterogeneity of the surface of the iron constitutes pairs, and the deposit of copper takes place upon the portions of this surface in which the heterogeneous molecules are situated. If perfectly pure iron were employed, this heterogeneity no longer existing, there would no longer be a pair, and the sulphate would no longer be decomposed. There happens here exactly what takes place for the decomposition of acidulated water with the zinc of commerce and with distilled zinc.

As the phenomena in question play a great part in the electro-chemical applications of electricity, and notably in galvanoplastics, we shall here quote some important observations of Fischer's, which will be serviceable to us further on.

Among the general circumstances, which influence the facility of reduction, Fischer mentions, besides the affinity of the reducing metal for the oxygen of the oxide of the solution, and that of the oxide formed for the acid of the solution, the reciprocal affinity of the reducing metal and the reduced metal; this affinity, according as it is powerful or feeble, whether it produces an alloy or a single mechanical union between the two metals, is able to favour the reduction or to prejudice it. The nature of the surface of the reducing metal, its density and its consistency, still further influence the reduction; a surface, covered with asperities, favours it; cobalt in powder, such as is obtained by the action of hydrogen upon its oxide, reduces the salts upon which it has not any action, to the state of buttons, that is to say, after having been melted. The form which the reduced metal assumes exercises a great influence in this way,—that if the latter, instead of forming a crystalline vegetation, as silver, lead, or of precipitating itself in the state of powder, as bismuth, deposits itself in the state of a film, which covers the reducing metal, it follows that this latter, no longer having any point of contact with the liquid, ceases to bring about the reduction. The greater or less degree of impurity in

the solution is able, according to the nature of the foreign substances that are found there, to provoke the reduction, which would not have taken place without their presence, or would have prevented it but for this; thus the presence of alkalis almost always prevents the reduction, when the oxide of the reducing metal is not able to be dissolved by them. But of all circumstances, the most important is the degree of purity of the reducing metal, to such a point that iron is a reducer in the majority of cases, as we had already remarked, only because it is never pure, and contains metals such as aluminium, silicium, &c., which form with it molecular pairs, as iron and lead form them with zinc in the zinc of commerce; these pairs determine the first decomposition of the salt of copper, and the deposited copper forms new pairs, which act in their turn, until all the iron being covered with copper, decomposition can no longer take place.

If we follow M. Fischer in the detailed experiments, that he has made upon the reduction of the reducible metals, by operating upon the various solutions of these metals, we find a great number of interesting facts very important to know for the applications, essentially in as far as gold, platinum, and silver are concerned. It follows, in particular, from these researches, that gold is so easily reducible that it would seem that the reduction is due still more to a positive property that it might possess, namely, to its tendency to regain the metallic state, than to its negative property, such as its less relative affinity for oxygen. Not only the other metals, but phosphorus, and especially carbon and silicium, reduce gold; sulphur also reduces it, but more slowly; nitrogen and hydrogen likewise reduce it. Gold, depositing itself in a thin film upon some metals, such as silver, it follows that the reduction soon stops; with others, it is deposited in the form of a brown powder, without metallic brilliancy, upon the reducing metal or upon the sides of the vessel; with copper, iron, zinc, cadmium, the gold forms a pellicle on the surface of the liquid. If, instead of the ordinary solution of simple chloride of gold, we employ that of a double chloride of gold and sodium, the reduction is brought about better and more promptly. Some acids, and their salts, also reduce

gold; such in particular are the salts which contain bases susceptible of assuming a higher degree of oxidation; for example, the sulphate of protoxide of iron, but in the state of hydrate, and not in the dry state.

Platinum is reduced by all the metals that reduce gold, except palladium, but in a much less prompt and much less perfect manner; it is sometimes deposited in a metallic film; but much more commonly under the form of a black powder, which appears to be a feeble oxide of platinum. Among the non-metallic bodies there is only phosphorus that reduces platinum; it likewise reduces it in the solution of the simple chloride, and in that of the double chloride of platinum and sodium.

The reduction of silver presents a great number of curious facts. The only metals that reduce silver equally in all combinations are zinc and cadmium; however, copper reduces also almost all the salts of silver, especially in their ammoniacal solutions, whilst tin does not act in the presence of ammonia; it is the same with bismuth and antimony, which, besides, do not reduce silver except in a small number of its solutions; iron reduces all the salts of silver, except the nitrate, at least when there is not a slight excess of acid — a phenomenon which is due to the slight film of oxide, with which the surface of iron becomes covered in nitric acid, and which constitutes its passivity. Among non-metallic bodies there is only phosphorus that reduces silver at the ordinary temperature.

Copper, like silver, is reducible by phosphorus; no other non-metallic substance is capable of bringing about its reduction. Among the metals, zinc is the only one that reduces all the solutions of oxide of copper in acids and in ammonia. Cadmium, iron, cobalt, and tin only reduce the simple salts, except the two former, which also reduce the double hydrochlorate of copper and ammonia.

We shall not dwell for the present upon the reduction of the salts of lead and tin, to which we shall be able to return further on in the Third Section.

If the influence of electricity is sensible in the phenomena

that we have just been describing, it is not the less so in the reductions brought about by a single metal, plunged by its extremities into two different liquids, which are themselves in communication by the intervention of a bladder, by which they are separated, so as to prevent their mixture. In these cases there is production of an electric current, sensible to the galvanometer, at the same time that there is decomposition of the solution and reduction of the metal, in the one that is metallic, if at least the latter liquid is water, either pure or slightly acidulated, and the reducing metal a metal easily oxidizable.

M. Becquerel has made great use of this latter mode of operation, in order to obtain a multitude of products, by means of small electric forces, acting for a greater or less length of time; these products are generally in the crystalline state. The learned philosopher employs two kinds of apparatus. The most simple are tubes about $\frac{1}{5}$th of an inch in diameter, closed at one end, at the bottom of which is placed a substance in powder, such as a peroxide, upon which is poured a metallic solution, into which is plunged a plate of another metal, that communicates by its lower extremity with the substance at the bottom; upon the surface of this plate are deposited in the crystalline state the different compounds to which the decomposition of the solution gives rise, joined to the secondary actions, that are brought about by the presence of the elements in the nascent state. Thus, in order to obtain protoxide of copper in the crystalline state, black bi-oxide of copper is introduced into the tube; upon it is poured nitrate of copper, which is not long in moistening the black bi-oxide; and a plate of copper is plunged into the solution; the tube is closed hermetically; and, at the end of a week, sometimes less, we perceive upon the part of the plate of copper, which is not in contact with the bi-oxide, small octahedral crystals of a ruby red; these crystals gradually increase in dimensions; and, after a greater or less length of time, finish by having a width of from $\frac{1}{25}$th to $\frac{1}{12}$th of an inch. Besides these crystals, metallic copper is deposited upon the plate of copper in beautiful octahedral crystals of great metallic brilliancy. If the

tube has a small diameter, and the quantity of oxide employed is very considerable, relatively to the solution of nitrate of copper, the latter is seen to be gradually discoloured, and to become limpid and colourless; there are then deposited upon the copper plate crystals of nitrate of ammonia in needles. The formation of the ammonia shows that the water is decomposed in this experiment, the variable results of which are due to the successive alterations which the substances contained in the tubes undergo. M. Becquerel has obtained by analogous processes, the oxides of lead, iron, manganese, &c.

The other class of apparatus, employed by M. Becquerel, which are a little more complicated, consists of a tube bent into the form of a U, filled in its lower part with clay, moistened with chloride of sodium, for example: into one branch of the tube is poured a solution of sulphate or nitrate of copper, into the other a solution of chloride of sodium; then, into each of them is plunged the end of a plate of copper, the other two extremities of the plates communicating together; the two openings are closed with a cork. In consequence of the reaction of the two solutions upon each other, and of the solution of the chloride upon the copper, there results a double electric current; the direction of which is such, that the end which plunges into the solution of the nitrate is the negative pole of the pair. The action of the current is sufficient for decomposing the nitrate of copper; crystallised copper is deposited upon the negative extremity; there is formed, besides, proto-chloride of copper, which combines with the chloride of sodium,—a combination, which gradually crystallises in tetrahedrons upon the positive plate. M. Becquerel likewise made use of the same U-tubes for forming sulphurets, either single or double; only instead of employing a single one, several are connected together, so as to obtain a pile. In one of the branches of each tube is placed a solution of nitrate of copper with a plate of copper, and, in the other, a solution of proto-sulphate of potassium, with a plate of copper, lead, or silver; these tubes are then united together into the form of a pile, so that the plate of metal of the solution

of sulphuret of one tube communicates with the plates of copper of the solution of nitrate of copper of the other, &c.; in order to increase the intensity of the current, care is taken to moisten the clay, that is at the bottom of the tubes, with the solution of nitrate of copper. With an apparatus, composed of a dozen tubes, we perceive, at the end of five or six hours, crystals of copper upon the copper plates, and octahedral crystals of sulphuret of silver upon the silver plate, if it is a silver plate that has been plunged into the sulphuret of potassium. It has even happened to M. Becquerel, that his apparatus, having acted for a fortnight without interruption, the silver plates have been entirely transformed into sulphuret of silver without having changed their form, only with an increase of volume. All the same effects are obtained with a single pair; only more time is necessary. It is evident that, in these experiments, there is a production of two currents travelling in the same direction; one due to the reaction of the two solutions upon each other; the other to that of the sulphuret of potassium upon the silver; there results from this a deposit upon the negative copper plate of small crystals of copper, arising from the decomposition of the nitrate, and transport of the sulphur upon the silver, with which it combines; when the silver plate is covered with the crystals of the sulphuret, the sulphur, still transported by the current, penetrates among their interstices and reaches the silver which is below; and this until it is all transformed into sulphuret.

This transformation constitutes a veritable *cementation* *, of which nature presents to us numerous examples; thus many metallic bodies, without losing their form, suffer an oxidation which, by virtue of slow actions, travels from the surface to the interior of the body, as far as the centre, gradually. This phenomenon, which can take place only so long as elements are transported from within outwards,

* By cementation is understood the molecular action, in virtue of which elements of different natures are introduced into the interior of bodies, whilst others are expelled, and this without the body losing its form.

whilst others are transported from without inwards, is attributed by M. Becquerel to electric forces, which, in his opinion, are the only forces capable of bringing about transports of this kind, which take place from molecules to molecules. The learned French philosopher has succeeded in obtaining several effects of this kind, by the direct application, prolonged for a long time, of very feeble voltaic currents. Thus, by constructing a pair with zinc and a cylinder of chloride of silver, plunged into a solution of chloride of sodium, he succeeded in gradually transforming the whole of the chloride of silver into metallic silver, without the form of the cylinder having changed. This electro-chemical cementation is analogous to that, which M. Darcet had observed at the Mint, where a bar of steel had been neglected in a closet, at a short distance from a flask containing a solution of sulphate of silver, which had a crack through which the solution gradually filtered. The latter, having reached the steel bar, had gradually reacted upon it; and, at the end of several years, the silver was so well substituted for the iron, that, in place of the bar of steel, nothing was found but a bar of malleable silver. It is evident that there was a formation of an infinity of molecular pairs, silver and iron, which had brought about the oxidation and solution of the iron, at the same time as the reduction of the silver. What is particular in this class of phenomena is, that the effect is not produced only at the surface, as, for example, in the case of the immersion of a plate of zinc or iron in sulphate of copper; but that there is an inter-molecular penetration and substitution of one metal for the other, without alteration of external form. The cementation by virtue of which iron is converted into steel by the penetration of carbon, is one of those which are most anciently known, and which have most fixed attention; it is generally attributed to the successive penetration into the iron of the oxide of carbon, formed in the combustion of the carbon; this gas, as soon as it is in contact with the iron, at an elevated temperature, abandons a part of its carbon, in order to be changed into carbonic acid gas, which

is expelled through the same interstices that have given passage to it.

Although electricity doubtless plays a part in the phenomena of cementation, we are disposed to believe that they are connected with a more general cause, which itself comprehends the voltaic effects. We know that certain substances, under the influence of heat, or even at the ordinary temperature, are able to exchange a molecular movement, so that there results from it a different grouping of the particles, or a new crystalline system; such are the crystals of sulphate of zinc, arragonite, &c. This motion, therefore, may take place without the body ceasing to remain in the solid state. Now, if we refer to the manner in which we have conceived the exercise of affinity in the production of a voltaic current*, we are able to admit that the molecules of a solid body can be polarised like those of a liquid; and that the current being established, there is an exchange of the constituent elements of the successive compound particles; hence, in the example quoted above of the steel and the silver, the particles of silver come successively to take the place of those of iron, without its being necessary to admit that the silver had penetrated among the pores of the steel. This polarisation of the particles of a body necessarily admits of the mobility of the particles which, as we have seen, ought to turn first their positive pole on one side, then afterwards their negative pole. Now, this mobility is, for solid bodies, as we have just said, a fact which cannot be called into question; for chemistry, like physics, furnishes several proofs of it, among which, besides those deduced from crystalline phenomena, we are able also to cite cases of the electro-chemical decomposition of solid bodies, such as sulphurets and iodides†, providing care is taken to heat them sufficiently, without rendering them liquid, so as to facilitate the relative motion of their molecules.

Among the natural phenomena which have an immediate relation to those which have just been occupying our attention, we will cite, with M. Becquerel, the powerful altera-

* Vol. II. p. 674. † Vol. II. p. 376.

tions which the impression of a mineral, called *pacos*, undergoes—a mineral that is found in the upper part of certain argentiferous veins, which is in varied masses of an argilo-calcareous and sometimes quartous nature; having a brown colour of greater or less depth, and containing silver, either in the state of chloride or in the metallic state. Upon certain specimens the silver forms dendrites or crystalline tubercles, the parts of which present little cohesion. When these specimens are compared with those of chloride of silver, the decomposition of which has been brought about, as we have seen above, we are struck with the resemblance that exists among them, in respect to the molecular state; we are led by this to admit a common origin in the mode of the formation of the deposit of silver. In order to bring these minerals to the state in which they are found, it was sufficient to find decomposable pyrites, water containing chloride of sodium, or even pure water, conducting carbonaceous matters and chloride, or sulphuret of silver. In the following Section we shall see the attempts, that M. Becquerel has made for extracting metals from their ores by an artificial process, analogous to the natural process that we have just been describing.

Upon studying more closely the circumstances, that accompany the formation in nature of several crystalline products, M. Becquerel has succeeded in demonstrating their electro-chemical origin, and in forming them artificially. Hence it is that, if pyrites are very frequently produced in turf-pits, this is due to the creation of voltaic pairs, by means of the carbonaceous matters in contact with the various compounds of iron, and especially with the proto-sulphates; phosphates of iron are likewise formed there. However, it is a very difficult matter, in these natural formations, to distinguish the part of the electro-chemical action from that of the purely chemical action. This is especially true when the effects are in question, that result from the action of solutions upon each other, or of that of a solution upon an insoluble and non-conducting substance. However, if the action commences by affinity alone, the electricity that is necessarily

produced, is not slow in exercising its part, in a greater or less degree, in the formation of the product. The following is an example also furnished by M. Becquerel. If a piece of rough porous limestone be plunged into a solution of nitrate of copper, the nitrate reacts upon the carbonate of lime; carbonic acid is liberated at the same time that nitrate of lime, which dissolves, is formed, and insoluble sub-nitrate of copper, which is deposited in crystals upon the surface of the limestone. The reaction gradually extends from the exterior to the interior, by an effect of imbibition; and does not stop until the sub-nitrate that is formed, having so obstructed the molecular interstices, capillary action no longer takes place. If the piece of limestone, covered with the crystals of sub-nitrate of copper, is plunged into a solution of alkaline bi-carbonate slightly diluted, there is formed, when the action is prolonged, a double alkaline carbonate of copper of a clear blue colour, which, being immersed in a solution of sulphate of copper, is decomposed, so that there results a bi-basic carbonate of copper, which has the exact composition of *malachite*, although it has not its entire appearance; this is due to the difference between the circumstances which accompany the artificial formation, and those which accompany the natural formation of this carbonate.

The natural actions are very complex; above all, they have for themselves time; for they are in general very slow actions, in which the presence of air, — that of water, either pure, or holding in solution a greater or less number of various substances, — the accidental contact of two bodies, and other circumstances also, play a greater or less part for determining the formation of new products. If we examine closely the various strata which constitute the superficial crust of our globe, we see that water is found in very large quantities in the different formations of this crust, and principally in the parts composed of sands, clays, or rocks, porous or cleft, or merely permeable to water. As these strata frequently extend to great distances, if there exists in the earth electricity having a sufficient tension, they may serve for transporting it to a distance, and even as far as the metallic

substances which compose the veins, and which conduct the electricity. We have already seen the experiments, which prove the conductibility of the earth. With regard to those intended to prove the presence of terrestrial currents, they are less easy. Mr. Fox and M. Becquerel have, however, succeeded in proving the existence of these currents, where two strata, of any nature whatever, are moistened, and the water of one holds in solution compounds that are not found in the other. In these strata, the presence is also necessary of conducting substances, such as carbonaceous matters, pyrites, galena. It has been vainly attempted to determine a general direction in these currents; they are partial currents, having a direction which depends only upon the relative position of the materials that concur in their production. But if they may not be considered as being able to exercise an action upon the magnetised needle, and, consequently, as concurring in the phenomena of terrestrial magnetism, we may, with some certainty, attribute to them the decomposition of certain substances, as well as the formation of new compounds, principally in the crystalline state; a decomposition and formation, which takes place by the effect of actions which, it is true, are very slow, but constant.

There exist also a host of daily phenomena, which are evidently due to the continuous action of air and water; such, in particular, is the alteration that is suffered by metals exposed to this action either in the atmosphere or in the earth; the presence upon their surface of an oxide, or of a foreign metal, greatly accelerates, it is true, the chemical action which they undergo by the production of a current. Iron and cast-iron are altered the more rapidly in proportion as there are some oxidized points upon their surface. Lead, as soon as it is in contact with an unoxidizable metal, such as gold, is immediately attacked, and is rapidly covered with a white powder of carbonate of lead. Silver, which does not suffer any alteration on the part of the moist air, becomes covered in inhabited places with a violet film of the sulphuret of the same metal, the sulphur being furnished by animal emanations; the effect takes place, in general, by cementation,

when the sulphur, which acts upon the silver, is itself in this state of combination. Silver, by a long sojourn in the sea, is changed into chloride. There are cases in which the alteration that the metal suffers is only superficial; such is the case with zinc, which, having been for a long time exposed to atmospheric influences, is covered with a film of sub-oxide, which, not increasing in thickness, preserves the interior from all alteration. The difference in this respect is great between iron and zinc, which is probably due to their different molecular state; iron, whose particles are in the main very mobile, as is proved by magnetic phenomena, and the change of internal structure that it presents, permits much more easily than zinc of the effect of cementation, which causes the oxidation, and every species of chemical alteration, to penetrate even into the whole mass, without their being arrested at the surface. M. Sorel has turned to account this feeble alteration of zinc, when once it is covered with a film of sub-oxide, for the purpose of preserving iron from the combined actions of air and water. With this view, he applies a film of zinc upon the surface of this metal, after having cleaned it in acids, which have been used for purifying oils; the oxide alone is removed; it is dried in a stove; the iron is then plunged into a bath of zinc in a state of fusion; should a particle of the zinc be even removed, the iron would not be attacked by moisture, on account of the voltaic action, the iron and zinc forming a pair, in which the iron is negative; but if the zinc were removed over a great extent, the iron would rapidly alter.

Davy, as we have seen*, had long previously conceived the idea of applying the same principle to the preservation of the copper which is employed for the sheathing of vessels, in order to preserve it from the corrosive action of the water of the sea: for, when a piece of polished copper is left in sea water, it is not long in becoming altered under the influence of the water, and the oxygen and saline substances contained in it. As the result of numerous experiments, Davy found that by soldering here and there small plates of cast-iron or

* Vol. II. p. 684.

zinc upon the surface of the copper, there was neither corrosion nor diminution in this metal, after several weeks of immersion in the sea, although it had even been exposed during this time to the motion of the tide; but, in order to arrive at this result, it was necessary that the surface of the protecting metal should be comprised between $\frac{1}{40}$ and $\frac{1}{130}$ of that of the copper; if it were less, for instance, comprised between $\frac{1}{200}$ and $\frac{1}{400}$, the copper suffered a loss of weight, which was greater in proportion as the protector was smaller. But he was not long in noticing that, the copper becoming the negative pole of the pair, there were deposited upon it alcaline and earthy substances, particularly carbonate of lime and carbonate of magnesia, upon which plants and shells fixed themselves; whence followed an increase of weight sufficiently great to retarded the progress of the ships. This inconvenience was found of such importance as to cause this method of preserving the copper sheathing to be renounced; and endeavours were made to arrive at the same result, by substituting for the copper a bronze composed of 94 parts of copper and 6 of tin (Muntz's metal), the particles of which are, as it were, so many small voltaic pairs. The trials, save some exceptions, showed the advantage of this substitution. However, it must happen that the corroding action of the sea water being exercised upon the particles of tin, whilst the copper remains intact, the latter ends by being changed into a spongy mass, which is in its turn also attacked. Furthermore, in all cases the copper is preserved only because, forming part of a voltaic pair, hydrogen is liberated upon its surface, which deoxidizes it, in proportion as the action of the sea water tends to oxidize it,—an operation which must terminate by altering its molecular condition in disaggregating it.

Attempts had been made to apply the same method of preservation to various objects in iron, and particularly to surgical instruments; but it had been renounced, seeing that the object was not attained; the protecting effect being incapable of being produced, except so long as there might be a formation of a voltaic pair, and consequently the pre-

sence of water or of some humid conductor; simple exposure in the air is not sufficient. The best mode of preservation, in these cases, consists in covering the object that we desire to preserve with a film of an un-oxidizable metal, gold or platinum. We shall see, in a subsequent section, the resources that are in this respect presented by the application of voltaic electricity, still reverting to the labours of Van Beck and Schoenbein, as far as concerns the galvanic precipitation of iron.

After this general glance cast upon the properties of electricity, which are essentially turned to useful account in chemical applications, we are about to enter into some more circumstantial details respecting those applications, the advantages of which have been established by experience, and which have become common; they may be classed under three heads:—Extraction and preparation of metals,—Application of metals in thin coatings,—and finally, Galvanoplastics on the moulding of metals.

Application to the Preparation of Simple Bodies.

Davy was the first who conceived the idea of employing the dynamic force of electricity for separating elements, united by a power of affinity too great for yielding to ordinary chemical forces. We have already seen how he succeeded in decomposing soda, potash, and almost all the alcaline and earthy oxides.* Potassium and sodium are obtained more easily, and in greater quantity, when mercury is employed for the negative electrode. With this view a cavity is formed in a fragment of potash or soda, slightly moistened; and it is filled with mercury; this fragment is then placed upon a plate of platinum, which is in communication with the positive pole of a battery, whose negative pole terminates in a platinum wire, which is plunged into the mercury. The alcali and the water are decomposed, and the radical of the alcali, in combining with the mercury,

* Vol. II. p. 344.

forms an amalgam, which is placed in oil of naphtha, in order to preserve it from the action of the air. Then, in order to obtain the pure metal, the amalgam is placed in a tube bent at the two extremities, from which the air has been previously expelled. By heating the extremity, in which the amalgam is situated, the mercury is volatilized, and the metal remains; in order to protect it from oxidation, the precaution is taken of preserving it in oil of naphtha. By operating in the same manner, but employing an ammoniacal salt (carbonate or hydrochlorate), Berzelius obtained the ammoniacal amalgam, which led him to believe in the existence in ammonia of a metal analagous to potassium and calcium, and which he named ammonium. The appearance of the phenomenon is, in fact, entirely favourable to this manner of regarding it, the mercury, into which the negative electrode is plunged, is seen to swell, to become thick, to assume a buttery consistency and a silver white colour, at the same time that the volume becomes five or six times more considerable. But, when this amalgam is withdrawn, it is rapidly converted into ammonia, with liberation of hydrogen, and the mercury assumes its natural state. MM. Gay-Lussac and Thénard, who had likewise carefully studied this amalgam, considered it as the result of the solution of hydrogen and ammonia in mercury; one thing is certain, that it is unable to acquire a permanent duration; and that we have never been able to isolate the ammonium.

We shall not dwell upon the various results obtained by Davy, which, while still demonstrating to him the existence of metallic radicals in the various alcaline and earthy oxides, did not enable him to collect a quantity of these new metals sufficiently large for him to study their divers properties; neither shall we return to M. Becquerel's method, who, by means of small but long-continued actions, succeeded in obtaining several of these metals in the crystalline state. We shall immediately arrive at the processes by means of which M. Bunsen has succeeded in preparing by the galvanic way, in a much prompter manner and in a much larger quantity, the greater part of the metals, of which we have been speak-

ing, and in particular magnesium, barium, aluminium, calcium, &c. M. Bunsen works upon the chlorides of these metals, either by dissolving them in water, so as to obtain a concentrated solution, the temperature of which he raises at the same time that he submits it to the decomposing action of the electric current, or by causing them to melt in the anhydrous state in a porcelain crucible highly heated; and employing for electrodes, coke-carbon, well burned, similar to that which is employed by him in his battery.

M. Bunsen considers that, in this class of electrolytic decompositions, it is necessary to have regard to the *density* of the current, that is to say, to its intensity divided by the surface of the electrode upon which the reduced metal is deposited; according to him, the facility that is possessed by the current of overcoming affinities increases with this density. The following is the arrangement adopted by M. Bunsen for obtaining a great density, capable of overcoming the most energetic chemical affinities. A carbon crucible, filled with hydrochloric acid, forms the positive electrode of the battery; this crucible is itself placed in a porcelain crucible, which is heated in a water-bath. In the centre of the carbon crucible is placed a small porous vessel, intended for receiving the liquid to be decomposed; a narrow plate of platinum, which is employed as a negative electrode, is plunged into it. Owing to this arrangement we see that the current radiates from the whole of the interior surface of the carbon crucible upon the very limited extent of surface of the platinum plate or wire. Under these conditions, chromium, manganese, and many other metals, are deposited with the greatest facility from the aqueous solutions of their chlorides. Thus it is that, by operating upon a solution of the proto-chloride of chromium, we are able to obtain metallic chromium in plates of 0·077 square inches; these plates are coherent but friable; the surface in contact with the platinum plate is perfectly polished and brilliant. Chromium, which can be obtained in a state of purity only by this method, perfectly resembles iron in regard to its exterior aspect. If we gradually diminish the intensity of the cur-

rent, the reduction of the metal gradually ceases; and its place is supplied by the production of the anhydrous protoxide of chromium. The chloride of manganese behaves exactly like the proto-chloride of chromium; metallic manganese may be obtained in plates of more than 0·154 square inches, friable, and brilliant on one side. This metal oxidizes in the moist air, almost as easily as potassium. By diminishing the intensity of the current, the black manganeso-manganic oxide is obtained, instead of metallic manganese. If an amalgamated platinum wire is substituted for the plate of platinum, we succeed in reducing barium and calcium, by operating with hot and concentrated solutions of the chlorides of these metals, acidulated with hydrochloric acid. The reduction of barium is more easily accomplished than that of calcium; for, in the case of calcium, the negative electrode of platinum is very speedily covered with a film of lime, which interrupts the current; it is therefore necessary, if we desire to obtain rather notable quantities of the metal, frequently to detach the film which covers the wire, and to amalgamate the latter anew. It is unnecessary to remark that we thus obtain amalgams of calcium and barium; whence the two metals are easily extracted by heating them so as to volatilize the mercury in a current of hydrogen gas.

Before passing on to the second process employed by M. Bunsen — that, in which we act, not upon aqueous solutions of the chlorides, but upon anhydrous chlorides, reduced to this state of fusion by a high temperature, we cannot pass over, without a critical observation, the influence attributed by the learned German philosopher to what he terms the density of the current. It is impossible for us to admit that a same current may have a greater or less power of decomposition, according as it is more or less concentrated. Its decomposing power can only arise from the energy of the electro-motive force, which gives rise to it, and not from its mode of distribution in the liquid that it traverses. The degree of concentration of this liquid, joined to the small extent of the negative surface, has no other effect than, on the one hand, to render the decomposition more rapid; and,

on the other hand, to accumulate upon a smaller space the metal coating that arises from this decomposition. It follows from this that the metallic elements are not attacked anew by the solution, which is always more or less acid, in proportion as they are deposited, as takes place when, being spread over a very extended surface, they form there a very thin film. This is exactly what takes place in the decomposition of acidulated waters, in which we perceive no gas upon the surface of the platinum electrodes, when the latter have a very large surface, and the current is not very powerful, although capable however of producing decomposition; the bubbles of gas are found so disseminated over these larger surfaces, and are consequently so small, that they are dissolved in the liquid in proportion as they are deposited; and yet we have a proof in the polarization of the electrodes that decomposition has taken place. We shall not insist upon this point; it would, moreover, be easy to show, in many ways, that the idea, that the specific properties of a current are able to vary with its density, cannot be admitted.

It was to the preparation of magnesium that M. Bunsen first applied his method, which consists in operating upon the melted chloride; Davy had obtained this metal by means of the combined action of the current and of mercury, which amalgamated with the metal, just in proportion as it was reduced; but more time was necessary for the magnesium than for the metals of the alcaline earths. By means of slow actions, M. Becquerel, in operating upon chloride of magnesium, in which was plunged a plate of platinum, serving as negative electrode to a battery feebly charged, had succeeded in obtaining upon this plate small octahedral crystals of a silver white, which possess all the properties of magnesium. M. Bunsen takes chloride of magnesium well dried; he introduces it into a crucible of varnished porcelain, the internal cavity of which is divided into two compartments by means of a partition of porous porcelain, which does not plunge entirely to the bottom; a porcelain cover, pierced with two holes, covers the crucible; these two holes are for the purpose of serving for the passage of the two carbon electrodes. As soon as

the chloride has entered into fusion, the two electrodes are retained respectively in communication with the poles of a battery of ten pairs of Bunsen's or Grove's, decomposition immediately takes place; chlorine is liberated in one of the compartments, and magnesium in the other; as this metal is less dense than the chloride, the precaution is taken of retaining it in the liquid, by means of notches divided obliquely from below upwards, that have been made in the carbon electrode, upon which it must be deposited; otherwise it would rise to the surface, and would be burnt. We are thus able to obtain, in a short time, a button of magnesium of the weight of several dozens of grains. It is a white metal, and brilliant like silver; it presents a crystalline fracture. It may be filed, sawn, and beaten out; at the ordinary temperature it is as ductile as zinc, with which it possesses many relations. Its density is 1·743.

Aluminium has been prepared by M. Bunsen, in the same manner as magnesium, by operating upon a double chloride of aluminium and sodium, seeing that pure chloride of aluminium does not melt, but is volatilized at a moderately elevated temperature. M. Deville, who, on his part, had prepared aluminium by an analogous method, that is to say, by the electrolytic decomposition of the double chloride of aluminium and sodium, had found, after many trials, great advantage in modifying the process that had been adopted by M. Bunsen for magnesium. The following is that upon which he decided. The decomposing bath is prepared by mixing in a porcelain capsule, heated to about 400° Fahr., 2 parts of the chloride of aluminium, and 4 parts of dry sea-salt pounded; the combination is soon effected with liberation of heat, and a very fluid liquid is obtained. He then fills with this liquid, to the same vertical height, a varnished porcelain crucible, and a very dry porous tube, placed in the middle of the crucible, the cover of which it traverses by means of a large hole, into which it is introduced, fitting tightly. This same cover is pierced with a slit, for allowing the passage of a wide and thick plate of platinum, which serves as the negative electrode; whilst a distinct cylinder

of gas-retort carbon, introduced into the porous tube, serves as positive electrode. Care must be taken to maintain the bottom of the tube porous to an inch or so distance from the bottom of the porcelain crucible, and to heat the crucible constantly, which, for precaution's sake, is introduced into a larger earthen crucible. As soon as the current of a battery is made to pass, aluminium is deposited with sea-salt upon the platinum plate; chlorine, with a little chloride of aluminium, is liberated in the porous vessel with production of smoke, which is made to disappear by introducing from time to time some dry and powdered sea-salt into the porous vessel. A small number only of pairs are necessary (two strictly are sufficient) for decomposing the double chloride, which presents but little resistance to the electricity. The platinum plate is removed from time to time, when it is sufficiently charged with the metallic and saline deposit, which is detached and melted in an earthen crucible. After the cooling this matter is treated with water, in order to dissolve the sea-salt; and a grey crystalline powder is obtained, which is collected into buttons by several successive fusings, employing as flux the double chloride of aluminium and sodium. At the end of the operation there is always found in the porous vessel a large quantity of carbon, which is detached from the positive electrode.

Aluminium, obtained in this manner, is never very pure, at least unless extremely pure chloride of aluminium is employed*; but M. Deville obtains it in a very great degree of purity, by preparing it by sodium. We are aware to what a degree of perfection the learned French chemist has advanced this mode of preparation, which he has succeeded

* M. Deville has remarked that, when an impure chloride of aluminium and sodium is decomposed by the battery, a metallic matter is obtained, which is generally aluminium, combined with a small quantity of carbon, and especially with silicium. The silicium separates from it with facility when this fused metal is attacked by the prolonged action of hydrochloric acid, concentrated and boiling. This silicium is in brilliant metallic plates, similar to filings of platinum. However, it is not a veritable metal; and M. Deville, who has prepared silicium in large quantities, by purely chemical processes, and who has studied all its properties, believes that this form of silicium is to ordinary silicium what graphite is to carbon.

in rendering very economical.* We are unable to dilate upon this subject, which goes entirely beyond our sphere; since a purely chemical process is in question. We shall confine ourselves to adding that aluminium is a metal, which, on account of its remarkable properties, will very probably end by coming into common use; and should we not be indebted to the voltaic battery for possessing it in large quantities, we shall at least be always indebted to it for the discovery of its existence. Aluminium, although of very feeble density (2·56 to 2·67, when it has been passed through the flatting machine), has great hardness and elasticity; it is white, like silver, only a little bluish; it is very malleable, very ductile, and a very good conductor of electricity. It melts at a higher temperature than zinc, but lower than silver. Hammer-hardening exercises a great influence over the properties of aluminium; thus, at the moment when it comes from being melted, it has the hardness of virgin silver, when nearly pure; when it has just been hammer-hardened, it nearly resembles iron for hardness and elasticity. It has, especially when pure, an excessive sonorousness; when suspended to a thread, and struck by a dry body, an ingot of aluminium produces the sound of a metal bell. But what renders it especially valuable for common use is the resistance that it presents to the action of acids, and the agents which attack the majority of metals in common use. It is even in this respect superior to silver, and especially to tin, the place of which it might advantageously supply in a host of economic uses. Moreover the electro-chemical rank of aluminium, which has been determined by Wheatstone in

* M. Deville has sufficiently perfected the fabrication of sodium that this metal costs him only about 3*s.* 6*d.* per lb.; he has also succeeded in making chloride of aluminium for about 1*s.* 1*d.* per lb.; but the cost price of aluminium itself has not yet been able to be fixed, on account of the imperfection of the apparatus hitherto employed, which caused more than three-fourths of the sodium and aluminium to be burned and destroyed in pure loss. It is to be hoped that he will succeed in avoiding these inconveniences, and in obtaining aluminium at a price not far from 1*s.* 9*d.* per lb., which is what the theory of the process indicates. It is understood that, in consequence of its small density, aluminium will be, volume for volume, of a much lower price than that of other metals, such as silver, with which it possesses so many relations.

London, and by M. Hulot, in Paris, truly places it among the number of the less attackable metals.

The method which has served for the preparation of magnesium and of aluminium, has likewise, with some modifications, been applied by M. Matthiessen to the preparation of calcium and strontium, as well as to that of lithium. In order to obtain strontium, M. Matthiessen places a little porous vessel into a small crucible; and after having placed in the two vessels some chloride of strontium, mixed with a little sal-ammoniac, so that the level of the melted chloride is a little higher in the porous vessel than in the crucible, he leads into this latter vessel the negative electrode, which consists of a very fine iron wire, coiled round a thicker wire, which is enclosed in a pipe tube, so that the latter wire does not pass more than $\frac{1}{10}$ of an inch beyond the lower extremity of this tube; the positive electrode is a hollow cylinder of iron, placed in the crucible, and which surrounds the porous vessel. The heat must be regulated during the operation, so that a crust is formed at the surface of the melted chloride in the porous vessel; the metal collects below this crust. Strontium resembles calcium in respect to colour; it is presented under the form of brilliant plates of a bright brass yellow, but deeper however than the colour of calcium. Its density is 2·54, whilst that of calcium is 1·578 at a mean; in the electro-chemical series strontium is found to be placed between calcium and magnesium. Like calcium, it easily decomposes water, oxidizes in the moist air, and burns with a vivid brilliancy when heated.

In order to prepare lithium, we have merely to act upon pure chloride of lithium, melted in a small porcelain crucible with a current of from 4 to 6 pairs, taking for the positive electrode a small rod of gas carbon, and for negative electrode an iron wire of the thickness of a netting needle. After a few seconds there is formed beneath the surface of the melted chloride a small globule of lithium, which is attached to the iron wire, and which, at the end of two or three minutes, attains to the size of a small pea. In order to obtain it, the iron wire is raised, with the globule which

is attracted to it, by means of an iron spoon. The wire is then withdrawn from the metal still melted, which is preserved from contact with the air by a film of chloride of lithium. After having allowed the spoon to cool under oil of naphtha, the metal is removed with a penknife. By repeating these operations every three minutes, we succeed in reducing in a very short time an ounce of chloride of lithium. This metal, when it has just been freshly cut, possesses the colour of silver; but it tarnishes rapidly on contact with the air. It melts at 356° Fahr.; it is harder than potassium and sodium, but is softer than lead, although, like lead, it may be drawn into a continuous wire. It is the lightest of all known metals; it floats on the surface of oil of naphtha; its density is 0·5936. Lithium is much less oxidizable than potassium and sodium; it inflames at a temperature very superior to that of its point of fusion; thrown upon water it oxidizes, but does not melt like sodium. Silicium, glass, and porcelain are attacked by lithium at a temperature below 320° Fahr.

We shall not dilate further upon the application of electric forces to the reduction of the alcaline and earthy metals; what we have said is sufficient to make its importance comprehensible. It is true that, in respect to the greater number of these metals, purely chemical modes of preparation have been found more economical, and, in some cases, more easy than the electro-chemical method; but, as we have already remarked, it is to the latter method that we are indebted for having, in the hands of Davy, discovered the existence of these metals, hitherto unknown; and it is not improbable that it will, at some time, come into more common use, when we shall have succeeded in procuring the electric current at a moderate cost.

However, M. Becquerel has already endeavoured to cause the employment of the electric current to enter into the domains of industry for the electro-chemical treatment of the ores of silver, lead, and copper. It would not be easy for us to give a complete description of the numerous trials made by the illustrious philosopher, and of the processes upon

which he has decided. All the details will be found in the second volume of his *Treatise on Electricity*. We shall confine ourselves to pointing out briefly the principles by which he has been directed, and some of the results that he has obtained, as the consequence of his numerous and persevering labours.

We shall not dwell upon the preparations, to which the ores are to be subjected, in order to render them capable of being treated electro-chemically; the treatment of the ores of silver, lead, and copper, by the moist way, rests upon the property possessed by chloride of silver and sulphate of lead of dissolving in a saturated solution of sea-salt (chloride of sodium), and by sulphate of copper of dissolving in water. It is, therefore, necessary to convert the silver in the ore into a chloride, which is accomplished in different manners, either by the moist way, or the dry way, or by roasting; this depends upon the state of combination of the silver in the ore; the moist way must be employed if the silver is in the metallic state, or in the state of the single sulphuret; the dry way is necessary if the silver is in the state of the double sulphuret. With regard to lead, it must be sulphated, which is accomplished by acting either by the moist or by the dry way upon the lead ore, which is generally galena or sulphuret of lead. There exists an argentiferous galena, the lead of which may at the same time be sulphated, and the silver made into a chloride by means of a roasting given to the ore, which is mixed with a certain proportion of sea-salt. Copper being found in the ores in a metallic state, as oxide or as sulphuret, it is necessary, in order to sulphate it, to employ the moist way in the two former cases, and roasting in the latter. Particular precautions are necessary for accomplishing the roasting, when, as in the most common cases, we are acting upon multiple sulphurets, and particularly upon copper pyrites, which is a combination of sulphuret of copper and sulphuret of iron.

The ores of silver, lead, and copper, being made into chlorates or sulphates, and the solutions of the metallic com-

pounds being made in salt water or simply in water, if copper is in question, we succeed in obtaining these three metals in the metallic state, either by plunging into their solutions more oxidizable metals, or by causing an exterior electric action to intervene. The first method, which consists in decomposing immediately the solution of chloride of silver, by means of iron, lead, or copper, is very imperfect, in that it does not enable us to reduce all the silver contained in the solution, and in that the reduced silver is never altogether pure. So that we shall not occupy our time with it; neither shall we with that which consists in precipitating the silver by lime, or by any other powerful base, and which is likewise not at all satisfactory.

In the electro-chemical treatment, properly so called, we employ voltaic pairs composed of zinc, iron, or lead, associated with plates of copper, tinned iron, or pieces of well-burned carbon, which are placed in immediate contact with the metallic solution; whilst the oxidizable metals are placed in a porous vessel, filled simply with salt water, and plunged into this solution, then placed in metallic communication with the copper, the tinned iron, or the carbon. From this voltaic combination, there results an electric current, which decomposes the chloride of silver, and which is even able to decompose other metallic compounds, if zinc is employed as the oxidizable metal; amalgamated zinc is still preferable. Mercury must also be employed in order to establish contact between the positive and negative plates on the one hand, and the conducting wire that is to unite them on the other hand. M. Becquerel has found that, on connecting a certain number of similar apparatus, so as to form a pile (of six pairs for example), the decomposition of the chloride is accelerated without increasing the expense. Thus, in the space of six hours, a plate of the apparatus, composed of six pairs, furnished 10·65 grains of silver; whilst, in the same time, a single pair, acting alone, furnished the half of this. In both cases equally, the silver was deposited upon the negative plate of the pair. We may likewise include in

the circuit of two or more pairs, similar to those of which we have just been speaking, an independent pair, formed of a plate of amalgamated zinc, and a plate of tinned iron; from this, there results a sensible increase of effect, especially if we take the precaution of heating to ebullition the independent pair; but then, for the tinned iron, which is attacked when heated by the saline solution, we must substitute a piece of carbon from gas retorts. Whatever may be the system employed, we always remark that, in the first power of the electro-chemical treatment, three-fourths of the silver is extracted, and that the remainder is extracted from the solution with much difficulty.

Without dwelling upon the treatment of the ores of lead and copper, for which M. Becquerel follows processes analogous to that of which we have just been speaking for silver, we shall confine ourselves to saying that it follows, from the numerous researches made by this philosopher, that silver ores may be treated without difficulty by the electro-chemical process, provided sea-salt is at a low price, and that there is a sufficiency of wood in the locality for carrying on a roasting, when the chloration cannot be accomplished by the moist way. However, in the present state of the electro-chemical method, the more simple system of Mexican or Freyburg amalgamation is preferred in practice. It would only be in this case, in which mercury should chance to fail that recourse would be had to the electro-chemical process, which is the only practicable one, when the treatment of argentiferous galena and argentiferous copper pyrites are in question.

However, although the employment of electric forces has not yet been able to assume a rank, on the large scale, for the extraction of metals from their ores; and although it remains rather a scientific process, there nevertheless exist many special cases, besides those which we have pointed out in this Section, in which this part of metallurgy may advantageously turn to account the action of a voltaic current; it is when the object in view is the extraction of the precious metals, such as gold, from solutions which do not

contain more than a minute quantity of it. In order to discover the presence of gold in a solution of this metal in aqua regia (nitro-muriatic acid) we merely require a zinc and platinum pair, the zinc of which plunges into a solution of sea-salt, separated from the solution of gold in which the platinum is plunged, by means of a little moist clay. The platinum has the form of a fine wire, the free end of which passes into a glass tube, which reaches about one-eighth of an inch beyond its extremity, which is closed at the lamp. Upon the end of the wire the gold is precipitated, which not only permits of our proving the presence of a small quantity of gold in a solution, but also of collecting it. We prove that no more gold remains in the solution, by substitution for the former platinum wire, a second one arranged in a similar manner; and, as soon as we are thus satisfied that the operation is terminated, the wire, covered with gold, is cut off flush with the tube; it is then weighed; the gold is dissolved in diluted aqua regia; the wire is weighed anew, and the difference gives the weight of the gold. All loss of gold is avoided, by fixing at the extremity of the platinum wire a capsule of the same metal of a very small diameter, the external surface of which is covered with varnish, in order that the gold, precipitating itself in the interior, may be collected entire.

The same process may be employed for separating gold from a solution containing other metals. In order to separate gold from copper, a copper and platinum pair is taken, the platinum of which is plunged into the solution of gold and copper in aqua regia, and the copper into a solution of copper in the same liquid, at nearly the same degree of concentration, separated from the former by a diaphragm of porous earth. The electric current, that results from the action of the proto-chloride of copper upon the copper, decomposes the chloride of gold, and deposits the gold alone, without a trace of copper upon the platinum. An experiment, in which a solution, containing half a grain of gold, was introduced into a concentrated solution of copper, showed that, by the process that we have been pointing out, we

might extract to nearly the hundredth of a grain, all the gold contained in the solution; for the platinum plate upon which the gold was deposited, and which weighed 3·458 grains before the experiment, weighed 3·936 grains after, which showed that the weight of the gold extracted was 0·478 grains. We are able, in the same manner, to separate gold from iron and lead, by taking, in the former case, a solution of proto-chloride of iron and a plate of iron or of copper, if the solution contains copper as well as iron; and, in the latter case, a plate of copper. We thus obtain the gold contained in the solutions to near the hundredth part of a grain. The employment of copper as the positive metal possesses the advantage of giving, when associated with platinum, in order to form a pair, a current which has only the power necessary for decomposing the chloride of gold, which causes the gold alone to be deposited upon the platinum, as may be proved in a direct manner by means of re-agents. We have dwelt upon these details, because in the arts in which gold is employed, and in particular in the art of gilding, and in that of colouring gold, it is of importance to be able to extract all the gold that remains, sometimes in minute quantities, in the solutions that are employed; the precipitation by iron and by sulphate of iron, which is the method employed for separating the gold, being insufficient.

The very great difference that exists between the electro-chemical properties of gold and those of the metals with which it is alloyed, had made me think that we might be enabled by forming a pair in very pure nitric acid with pure gold and alloyed gold, to determine the character of the alloy by the degree of the intensity of the current. Several trials that I have made, while still giving me satisfactory results, have remained, with regard to precision, below the ordinary methods. M. Oersted, who was the first who attempted this mode of making assays by applying it to silver, had likewise found that it can be only an approximative process. However, it may present some advantages in certain particular cases, in which the other processes are applicable with difficulty.

Applications to the Formation of Metallic Deposits in thin Films.—Gilding, Silvering, &c.

We have seen, in the First Section, that, when we plunge into a metallic solution a more oxidizable metal than the one that is in combination, this latter is precipitated in the metallic state, forming upon the surface of the former a deposit, sometimes pulverulent, at other times more or less adherent; we have remarked that these effects arise from the simultaneous concurrence of affinity and of electric forces. This kind of actions had already been, for a very long time, turned to account for producing adhering deposits in certain particular cases; but the most remarkable is that of the tinning of pins; for, in this case, contrary to the principle that regulates the precipitation of metals, it is the more oxidizable—the tin—that is made to be precipitated upon the less oxidizable, copper or brass. But, in order to obtain this result, it is not chemical affinity alone, but the voltaic power of a pair, that is employed. In fact, a parcel of untinned pins are thrown into a solution that contains, with various salts, oxide of tin; no effect is produced, whatever be the duration of the immersion; but as soon as a piece of tin is thrown into the solution, which touches one only of the pins, which are, moreover, all in metallic contact with each other, the whole parcel are immediately tinned. Those pins that are not in metallic contact with the tin are not tinned. It is evident that there is here the formation of a voltaic pair, which decomposes the salt of tin, and transports the tin upon the brass of the pins, where it forms an adhering deposit. This adherence is not always easy to be obtained; in the tinning of iron it is obtained by plunging the plates of sheet iron, the surface of which has been previously well cleaned, into a bath of tin, covered with matters in fusion, which prevent oxidation; it is the same for the zincing of iron; however, in this case, the electro-chemical process is preferable. Pressure or friction likewise produces adherence in the case of plated goods, by bringing about a more immediate contact among the parts.

The gilding of metals is, of all the operations whose object is to obtain an adhering deposit, the one which has exercised in the greatest degree the sagacity of inventors; gilding, by simple immersion in a very diluted neutral solution of chloride of gold, was one of the first methods employed for copper, and for iron that had been previously covered with a coat of copper. It was the same for plating; but these processes of gilding and plating give only films of gold and of silver, that were but little adherent, and very thin. Recourse was therefore generally had to gilding by mercury, which consists in covering the article to be gilt (copper, brass, or silver), after having carefully cleaned it, with an amalgam of gold, then passing it into the fire; the mercury, by evaporating, leaves the gold on the surface of the article in a film, more or less thick, and perfectly adhering. But, in the practice of this process, the workmen, incessantly exposed to the contact of liquid mercury, or to the action of mercury in a state of vapour, suffer in the highest degree the inconveniences of poisoning by mercurial emanations. It is true that the very powerful blast furnaces, contrived by M. Darcet, avoid in great part this inconvenience, but not totally; and, besides, they are, unfortunately, not in general use.

Mr. Elkington had devised a process of gilding by immersion, much superior to those which had been practised formerly, and to which we shall return, when in 1840 I made known the results that I had obtained, by employing electric force in a direct manner, for the gilding of metals. I had, as far back as 1828, succeeded in gilding platinum and silver wires, by employing them as negative electrodes in a solution of chloride of gold; but I had not continued this class of researches, when the effects of galvanoplastics, which will form the subject of the following Section, made me presume that an analogous process to that employed in this new art might serve for gilding. The following is this process. I placed the object to be gilt (silver, copper, or brass) in a very diluted solution of chloride of gold, contained in a cylinder of bladder or gold beaters' skin, plunging this into a flask filled with water slightly acidulated, in which is situated

a hollow cylinder of zinc, that surrounds the cylindrical bladder. The zinc is placed in communication, by means of a wire, with the object to be gilt, which has previously been carefully cleansed. The gold is deposited upon this object, which is, in fact, the negative electrode of the pair, and adheres to it, more or less powerfully, whilst the zinc is dissolved in the acidulated water. The solution of gold must be as neutral as possible, and diluted with distilled water in such proportions that there are 0·075 grains of gold in a given bulk of the solution. We can form an idea of the small quantity of gold which this process requires, by the following experiment, in which ten silver coffee spoons were gilt with a quantity of the solution, which contained 12·3 grains of gold; and yet the solution was far from being exhausted, for it still preserved its yellow colour. Supposing, however, that the ten spoons had abstracted all the gold, each spoon would have taken up 1·23 grains; which, by setting gold at the price of twopence-halfpenny a grain, causes the price of the gilding of each spoon to amount to threepence. The operation must be performed in two or three immersions, and great care must be taken to rub the object with fine linen, every time that it is withdrawn from the solution. The colour of the gilding depends upon the character of the dissolved gold, and also upon the nature of the object to be gilt; it is redder upon brass than upon silver. In order to obtain a very brilliant and very adhering gilding, we must rub with linen or leather, and even employ the burnisher.

Without dwelling upon the different details of this process, we may remark that it possesses the inconvenience of allowing a little gold to be reduced by the zinc of the pair and by the bladder, which serves as a diaphragm; that, moreover, the gilding is frequently but little adherent, which is due to the circumstance that the solution of gold is never sufficiently neutral, not to exercise a slight chemical action upon the surface of the metal to be gilt, and not, consequently, to alter its cleanness. I had succeeded in diminishing these inconveniences, and, in particular, in rendering the

solution more neutral, which had enabled the process to give satisfactory results in the hands of skilful workmen, when MM. Elkington and Ruolz introduced into this new art improvements, which have ended by rendering it sufficiently common for it to have generally taken the place of mercurial gilding.

Two essential points characterize these improvements: the first, the employment of a solution of gold other than the ordinary chloride; the second, that of a battery substituted for a simple pair, which avoided the presence of zinc in the same vessel in which the solution of gold is, and consequently renders the intervention of a porous diaphragm no longer necessary. This mode of applying the electric force to gilding is the one of which I had conceived the idea in my first trials in 1828, and which I had renounced, wrongly hoping for more economy and more facility of manipulation in the employment of a simple apparatus.

Mr. Elkington, as we have said above, had commenced by producing the gilding by the moist way, without the direct intervention of electricity. In concert with Mr. Wright, he had made several experiments, from which it resulted that the best means for bringing about this kind of gilding, consisted in dissolving the gold in aqua regia, and mixing with the perchloride, that was the result of this, a great excess of bicarbonate of potass, causing the whole to boil for a very long time. Pieces of well-cleaned brass, bronze, or copper, are then plunged into the boiling liquors, and the gilding is immediately applied, a part of the copper of the article dissolving, in order to take the place of the gold that is precipitated, as in other analogous cases. It appears that the selection of the bicarbonate of potash greatly influences this result; it is best, in order to the operation's going on well, that it should not be too pure, and that it should contain some organic matters, which facilitates the reduction of the perchloride to the state of protochloride, towards which the long-continued boiling of the solution, with that of the bicarbonate of potash, tends to bring it, and which suits the gilding much better. The inconvenience of this process is

that, necessarily, the gilding has a limited thickness, since when once all the surface of the metal to be gilt is covered with gold, it can no longer be precipitated, as we have seen and explained in our First Section. In fact, it follows from comparative experiments, made with great care, that the best gilding, by the moist way, has been able to fix only 0·651 grains of gold upon a given surface; whilst the poorest mercury gilding fixes 0·66 grains; so that gilding by the moist way, in the most favourable case, scarcely reaches the degree of thickness to which the worst mercury gilding is obliged to attain; which makes it impossible that the former can become a substitute for the latter.

The inconvenience, that we have just been pointing out, is in no way applicable to Mr. Elkington's second process, which consists in plunging the object to be gilt as negative electrode of a constant battery, the positive electrode of which is platinum, in a solution containing 482½ grains of gold, converted into oxide, 7723 grains of ordinary cyanide of potassium, and 244 cubic inches of water, which are boiled together for half an hour. The liquid thus obtained gilds very rapidly when it is boiling, and more slowly when cold. By this process we are able to increase the thickness of the layer of gold at pleasure, and to account for this thickness by the duration of the immersion.

On December 8th, 1840, Mr. Elkington took out his patent for his second success; on December 19th, of the same year, M. de Ruolz likewise took out one for gilding by the battery; his trials had led to such a variety of solutions of gold, that he finished by finding those which are at once the least costly and the most suitable; that is to say, the double chloride of gold and sodium dissolved in soda; chloride of gold dissolved in yellow ferro-cyanide of potassium; sulphuret of gold dissolved in neutral sulphuret of potassium. It is very singular that this last solution is one of the best, particularly in the gilding of bronze and brass, which are so easily attacked by sulphur. In practice, generally, the solution has been adopted that contains 1 part of dry chloride, 2 of yellow ferro-cyanide of potassium, and 100 of water. Sometimes

10 instead of 2 parts of ferro-cyanuret are introduced; but it appears that inconvenience is experienced when the cyanuret is too abundant, since the gold is partly redissolved in proportion as it is precipitated upon the object to be gilt. We shall, besides, return a little further on to this question of solutions. Let us first examine the advantages of gilding by the battery, brought about by means of M. de Ruolz's solutions, as may be gathered from the report of the Commission of the Academy of Sciences, as the result of experiments made under its direction.

Not only platinum, silver, copper, brass, and bronze, are gilt in the easiest and most regular manner; but mosaic gold, steel, and iron, are likewise gilt, which constitutes a great industrial advantage, on account of the very extensive use of these metals. Tin, it is true, in order to be well gilt, requires to be previously covered with a small pellicle of copper, which is easily accomplished by means of the battery and a solution of copper; it is then gilt as easily as silver, and constitutes one of the most beautiful gildings. Independent of the generality of its application, the gilding in question is of a solidity and equality that will stand any test; thus, a capsule of gilded brass has been seen to resist very efficaciously the action of boiling nitric acid. In fine, not only is the precipitation of gold perfectly regular, but it is exactly proportional to the time of the immersion; which enables us to judge of the thickness of the gilding by the duration of the immersion, and to vary it at pleasure. Thus, in three successive immersions, of two minutes each, of a same plate of polished silver, with a surface of 7·75 sq. in., a quantity of gold, amounting to 9·72 grains, was found to be deposited each time; the solution was composed of 1 grain of dry chloride of gold, dissolved in 100 grains of water, containing 10 grains of yellow ferro-cyanide of potassium. The battery was a Daniell's battery of six pairs. In the experiment that we have just been quoting, the temperature of the solution was 140°; in another experiment, made under the same conditions, except that the temperature was 95°, the quantity of gold deposited was, for each immersion

of two minutes equally, only 0·43 grains; but it always remained the same for each of the twelve immersions, that were made; we see that temperature, as we have already remarked, exercises a sensible influence over the rapidity with which the deposit is formed.

Plating is produced as easily as gilding; the best solution is that which contains 1 grain of dry cyanide of silver dissolved in 100 grains of water, containing 10 grains of yellow ferro-cyanide of potassium. All metals are as easily plated as they are gilt; it even requires a less powerful current (four pairs, instead of six, are sufficient); the plating is perfectly adherent and regular, and the thickness of the layer is also proportional to the duration of the immersions; the elevation of temperature accelerates the operation, as for gold.

When the object in view is to apply platinum, the cyanide, the decomposition of which is brought about very slowly, must be replaced by the double chloride of platinum and potassium, dissolved in caustic potash; a solution is thus obtained, which enables us to platinate with the same facility and the same promptitude as when the gilding or plating is in question. Platinum is so extensible that 0·015 grains is sufficient for covering uniformly a surface of 0·08 square inches with a film of platinum, which consequently possesses only 0·0000004 inches in thickness, and which is, however, sufficient for protecting the metal that has received this deposit.

M. de Ruolz has not confined himself to the application of the precious metals; he has succeeded also in coppering, leading, tinning, and zincing various metals in common use. For coppering, the double cyanide of copper and potassium is employed; only more time is necessary for coppering than for gilding and silvering. The leading of iron and that of other metals is produced by means of a solution of oxide of lead in potash. The tinning of copper, brass, and iron is likewise made with a solution of tin in potash or with the solution that is employed in the tinning of pins, which is formed by dissolving tin in cream of tartar. A

single pair suffices for producing the deposit of tin, except when zinc is in question, which requires several in order to its being tinned. Zincage, in general, requires only one, which is employed for the decomposition, either of sulphate of zinc or of oxide of zinc dissolved in potash. Previously to M. de Ruolz, M. Sorel had already introduced into the arts the zincage of iron, either by the dry way or the moist way. The deposits of cobalt and nickel are also accomplished according to the same process, likewise with alkaline solutions; these kinds of application have not yet been very much turned to useful account in the arts.

After this rapid glance upon the improvements introduced into the art of applying the metals upon each other, let us return, with somewhat further details, to that which concerns the application of the precious metals, and that of gold in particular; seeing that it is especially the practice of gilding, the adoption of which is so general, which has undergone the greatest amount of modifications in respect to new processes.

A short time after my first publication of the application of electricity to gilding, M. Boettiger had described a simple apparatus, analogous to mine, with which he had succeeded in gilding very well, not only silver and copper, but iron and steel, provided that these two latter metals were very well cleaned. He made use of a very diluted solution of chloride of gold, as neutral as possible, placed in a glass tube, closed in its lower part by a diaphragm of bladder. This tube is itself placed in a wider flask filled with water slightly acidulated, and at the bottom of which is a disc of amalgamated zinc, which is placed in communication, by means of a wire, with the object to be gilt, itself plunged in the chloride of zinc. M. Becquerel, notwithstanding the incontestable superiority, in the majority of cases, of the compound apparatus, considers, however, as does M. Boettiger, that the simple apparatus may also have its utility. The following is that which he recommends, in order to avoid endosmose, and consequently the loss of a part of the solution of gold. A bell-glass (*fig.* 424.) is taken, having in

its lower part a rather wide neck, which is filled with kaolin or with common clay, retained by a linen cover fixed around the outer side of the neck by means of a string. The neck of the bell-glass is then placed in an opening formed in the

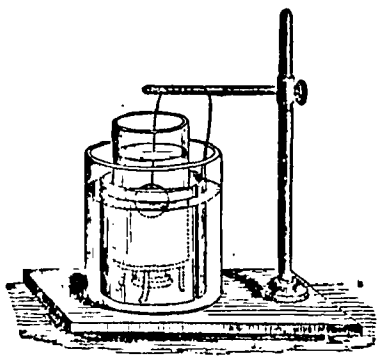

Fig. 424.

middle of a disc of wood, supported by three feet; the bell-glass, filled with the solution of gold, is then introduced into a glass or china bottle, containing a more or less concentrated solution of sea-salt, so that the two solutions are at the same height, in order to avoid the passage of one of the liquids from one vessel into the other. A plate of zinc is plunged into the solution of sea-salt, and the object to be gilt into the solution of gold; establishing communication between them by means of a wire. If we desire to avail ourselves of the action of heat, the whole is placed in a vessel filled with water, which is placed upon a stove. In order to obtain a uniform gilding, it is necessary that, as much as possible, all the parts of the surface to be gilt should be placed in the same manner, in respect to the zinc, which is more difficult to obtain in the apparatus of *fig.* 424. than in that which I had employed in my first trials, in which the chloride of gold was placed in a cylinder of bladder, enveloped by a concentric cylinder of zinc. In the apparatus of *fig.* 424., it is merely necessary that the cylinder of zinc should surround symmetrically the neck, and the article

should be frequently turned in order to make the action regular.

The simple apparatus may be employed when the only object in view is to gild articles of small dimensions. We may even, in this case, be content with placing a plate of zinc in contact with the object to be gilt, by plunging them together for a moment in a solution of gold. The operation is accomplished, in a glass or porcelain vessel, by heating the solution even to the boiling point, if we desire to obtain a good gilding. A rod of wood is placed upon the vessel, to which is adjusted a plate of zinc bent, the two extremities of which alone touch the solution; it is with this plate that the object to be gilt is placed in contact before the immersion. It is necessary to take the precaution of cleaning, from time to time, the immersed extremities of the plate of zinc, in order to remove the precipitated gold. Silver, copper, brass, and mosaic gold are gilt very well in this manner; in order to obtain an equally good gilding upon iron and steel, the precaution must be taken of plunging them first into nitric acid, diluted with water, in order to clean them well.

The compound apparatus, notwithstanding some advantages that may be presented by the simple apparatus, are much more generally employed. The following arrangement may be adopted for these apparatus. The vessel *a b* (*fig.* 425.), containing the solution of gold, is placed upon a stove,

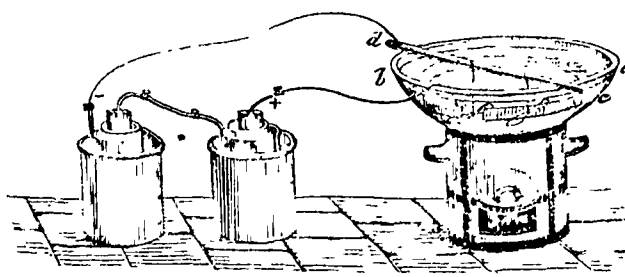

Fig. 425.

in order that we may be able to raise the temperature. A copper or brass rod, *c d*, rests upon the edge of the vessel, and is intended to support with hooks the objects to be gilt.

A plate of gold, serving as positive electrode, which permits the gold to dissolve, in proportion as it is reduced at the negative electrode, surrounds the vessel interiorly. The battery is composed of two or a greater number of pairs, according to the number and size of the articles to be gilt. The wire, that comes from the positive pole, communicates with a gold wire soldered to the plate that plunges into the vessel; and the wire that comes from the negative pole is placed simply in contact with the metal rod that rests upon the vessel. Attempts have been made to substitute for the battery a magneto-electric machine, producing induction currents, all guided in the same direction; but, as the current that is required is not of a very great intensity, the expense occasioned by the employment of the battery is not sufficiently considerable for it to be necessary to have regard to it in operations of this kind. It is not, however, impossible that hereafter advantage may be found in the employment of induction currents for industrial application. Messrs. Elkington have already done so to a considerable extent.

One of the most important and the most difficult points to obtain in electric gilding, is the perfect adherence of the deposit. For this purpose, it is necessary to take great care to scour and to cleanse the article to be gilt, that is to say, to clean its surface perfectly; this scouring consists in heating it, and then removing the film of oxide that is formed, by means of acids. If, after the scouring, the surface is not clean, it may be immediately cleansed by concentrated nitric acid, then in a mixture of this acid, sea-salt, and soot. The processes of scouring and cleansing vary with the nature of the metals subjected to the operation, and according as we desire to obtain a polished or a dead surface. When once the surface is well clean, we must avoid its remaining too long in the air; for one of the causes most opposed to adherence is the presence of a thin film of air upon the surface that is to receive the deposit. Too great an intensity in the current is also detrimental to it. It seems that, in order that the metallic deposit may be very adherent, it is necessary for its molecules to be able to come and lodge,

without trouble, in the molecular interstices of the body that it covers. It is not a combination that is brought about, but an effect of aggregation and cohesion; for we are able, by physical forces, to remove the deposited gold in a leaf, which is accomplished with the greater difficulty in proportion as the layer is thicker; thus, when we are unable to obtain a perfect adherence, we have only to give a little more thickness to the layer of gold. The employment of mercury greatly contributes to the augmentation of the adherence; thus, in electric gilding, the process already pointed out by M. Darcet for gilding by the fire is employed with advantage, — a process which consists in dipping the cleansed articles into a diluted solution of proto-nitrate of mercury immediately before plunging them into the gold solution. M. Becquerel remarks that, when the precaution has been taken of well whitening an article by several successive immersions in the solution of proto-nitrate of mercury, by rubbing it with a very soft skin, in order to spread the mercury well, the electro-chemical gilding that it receives presents a dead aspect; the dead and the polish being for gilding, according to M. Becquerel, only the result of the primitive deadness or polish of the surface to be gilt. There also exist in gilding several appearances that depend upon the intensity itself of the current, independently of the nature of the solution and of that of the metal to be gilt, which is due to the variations in the molecular state of the film of gold deposited. Thus we are able, by diminishing gradually the intensity of the current, to see the deposit of gold pass successively, and by shades frequently insensible, from brownish black to purple black, to brown, red, yellowish red, and finally to the yellow gilding, which is the most perfect, that is to say, that whose adherence is the greatest.

Among the applications of gilding, one of the most important in the arts is the gilding of the different parts of a watch. This gilding must be very solid, in order to be able to resist the friction that the different pieces of a watch movement undergo; so that fears at one time existed of our being compelled to renounce the employment of electric

gilding in this case, and to continue to make use of the mercurial gilding; which, in addition to the inconveniences already pointed out in respect to health, possessed that of risking the alteration in form of the pieces, which are in general very delicate, from the necessity that existed of exposing them to the fire. This inconvenience, joined to that which resulted from the alteration of the temper of the steel pinions fixed to the wheels, by the effect of their exposure to the fire, had even led to renouncing the gilding of the wheels of watch movements. It resulted from this, that not only did the wheels, which are of brass, become tarnished and black, which has a very disagreeable effect, but the brass wore the steel pinions; for brass possesses the unfortunate property when it is exposed to a continuous friction upon steel, of wearing this latter metal, and sometimes even gripping it, which does not take place with gold, probably on account of the absence of the formation of oxide. It was, therefore, very important to surmount the difficulties still presented by electric gilding, so as to be able to apply it to watch movements; success in this has been attained, as we are about to indicate by entering into certain details.

Watchmakers generally hand over to the gilders the pieces that are to be gilt, well polished, without any mark; now, as there sometimes remains after this polishing a slight film of grease or oil, it is necessary to cause these pieces to pass previously into a boiling solution of soda, in order to remove the grease from them; without doing this the risk would be run that the film deposited would not be adherent, and that it might present green spots, by the combination of the oil with the potash of the salt of the solution. This is not all, it is necessary, before applying the gilding, to grain the piece, that is to say, to produce upon it that dotted appearance which custom has introduced, we scarcely know why, but without which the gilder would see his work refused. This graining, for various reasons too long to enumerate, cannot be accomplished in hollows by removing metal by acids. It is necessary that it should be produced in relief, by application of metals; and, for this purpose, an excessively fine

powder of silver is employed, which is procured by various methods, some chemical, others mechanical, but which the gilders find ready prepared in the trade. One part by weight of this powder is mixed with twelve parts of common salt, very dry, and very finely sifted, four parts of cream of tartar, also very finely sifted; then, when the mixture is intimate, water is added, so as to form a clear paste; a brush is plunged into it, which is like a clothes-brush, but the hairs of which are closer and finer. When the brush has been well impregnated with the paste, it is employed for brushing the dotted pieces upon a disc of cork, care being taken not to rub them always in the same direction, for fear of having an elongated grain, whilst it is necessary that it should be round. If we rub too long, the grain becomes too large; it is necessary to limit one's-self to rubbing for one or two minutes. The proportions of the salt and cream of tartar of the mixture may vary, according to the object that is proposed; thus, if more cream of tartar than the portion indicated above is placed in, a finer and more compacted grain is obtained; we are even able to succeed in obtaining a grain which gives a dead gilding, by placing, for one part of silver, eighteen of kitchen salt and eight of cream of tartar. When once the piece is grained, *scratch-brushing* is required, an operation that is accomplished by means of an instrument in the form of a pencil, which is named a *scratch-brush*, and which is made of very fine brass wire; the grained piece is rubbed with this species of brush, care being taken that the surface be moistened with an astringent liquid, such as an infusion of horse-chestnuts; a brilliant grain is thus obtained, and the piece may then be gilt. Gilders for watch-work have for a long time employed either the Ruolz solution, or that pointed out by Boettiger, and which is obtained by dissolving dry chloride of gold in a solution of cyanide of potassium, prepared after Liebig's method, or others besides; but experience has pointed out to them that the one which produced the best results was the solution of ammoniuret of gold in the white cyanide of potassium; it is remarkable by the beautiful colour of pure gold that it presents, by its easy

preparation *, and by all the tints that it is able to procure, on being alloyed with silver and copper.

We shall not return to the operation itself of gilding, which is accomplished in general according to a process analogous to that which we have described in *fig.* 425. What is of most importance is, to know how to find the intensity of current suitable for obtaining the best gilding. For the same bath is able, according to this intensity, to give four or five different shades. The colour of gold most difficult to obtain is that of gold of 18 carats,—a tint that is desired to be given to watch cases that are gilt. Workmen, in general, content themselves, for appreciating the intensity of their current, with estimating approximately the quantity of oxygen that is liberated at the positive electrode,—a valuation altogether inaccurate, on account of the variable extent and nature of this electrode, which is sometimes of gold, sometimes of platinum, sometimes even of copper. What would be necessary would be to adapt to each battery a galvanometer and a rheostat, which enables us to find for each case the desired intensity †; it would be expedient, likewise, to have instruments of more convenient manipulation for the mere workmen, than those used for scientific purposes; we do not think that this would be a difficult thing to discover.

The same bath may, therefore, give a series of different colours, according to the intensity of the current; the greater

* In order to prepare this solution, the chloride of gold obtained from a ducat is dissolved, treated by nitro-muriatic acid, in 12·2 cub. in. of water; about 463·1 grains of ammoniacal liquid are added, stirring with a glass tube; a precipitate of ammoniuret of gold is formed, which is fulminant when dry; so it must not be dried: the operation is confined to filtering and washing the precipitate, until the water that passes no longer possesses the slightest dirty appearance. Then the filter containing the precipitate, still moist, is plunged into a solution of cyanide of potassium, which contains 154·3 grains of cyanide for the quantity of gold corresponding to the ducat, which makes three times the weight of the gold. The whole is kept boiling with 30 cub. in. of distilled water, which is supplied in proportion as it evaporates, until the bath has completely lost its ammoniacal odour; the bath is then withdrawn from the fire; it is filtered, and is ready for use on diluting it more or less; the colours are more brilliant with a concentrated bath, but a more powerful current is necessary.

† For this idea we are indebted to M. Mathieu, of Locle (canton of Neuchâtel), who has published a practical treatise on galvanic gilding, from which we have borrowed several details.

this intensity is, relatively to the surface to be gilt, the redder is the gilding. In order to obtain a pale gilding, it is necessary to add silver to the bath; if the quantity of silver added is $\frac{1}{14}$, the gilding is pale already; but, if it is $\frac{1}{12}$, we have a green gold. As silver is deposited more easily than gold, it is necessary from time to time to add some, but in a very small quantity, in order that the gilding may remain pale. In order to obtain it red, it is better to copper the object before gilding it, rather than to place copper in the solution; for we should then have a dull brown gilding. We may mention that a bath which has been employed, and which is already tolerably exhausted of gold, gives a redder gilding than a new bath. The ordinary colouring, which consists in acting upon the gold with a mixture of certain salts*, cannot be usefully employed upon electric gilding; in fact, in this gilding, the gold applied is generally fine gold, without alloy, upon which the action of the mixture is null; the colouring can only be really useful for gold of $\frac{750}{1000}$, or lower, since the salts have no other effect than to dissolve the metals attackable by them, and to place the fine gold bare at the surface of the object.

Touching the different shades that gilding may assume, it will not be useless to return for a moment to the manner of obtaining the deadness, which, as we have said, is the consequence of the surface to be gilded being itself dead. Now, there are many methods of rendering the surface that is to be gilt dead: mechanical means, by employing small instruments on broaches of copper, having little points at their extremities, which are impressed upon the metal: chemical means, by corroding the surface by acids or mixtures of salt. But the two methods which are best suited to electric gilding are: first graining the surface that is to be gilt with silver, according to the process that we have indicated, and

* The following is the composition of the mixture generally employed for colouring gold:—

Nitrate of potash	40 parts.
Sulphate of alumina	25
Chloride of sodium	35
	100

also covering this surface with a thin film of copper, by means of the decomposition of sulphate of copper, produced by a current of a suitable intensity, which also produces a very beautiful deadness, that is reproduced upon the gold film. A very beautiful dead gold is likewise obtained in gilding dials, or other whitened pieces of silver;—a whitening that is produced by plunging the silver or plated object into a boiling solution of 3 parts water and 1 part sulphuric acid, after having heated it almost to brown red, but when it is no longer red. Then, after having left it about thirty seconds in this boiling bath, it is washed in hot water, and is plunged into alcohol, in order to remove the water; it is then wiped with fine linen. Care must be taken to hold the article that is required to be whitened with a platinum or gold wire; without this, it would become spoiled in the bath.

It frequently happens that, in the objects to be gilt, there are portions which must not be; and which, consequently, must be covered with a varnish, that prevents the gold from being deposited upon them. The composition, and the mode of application of this varnish, are not without importance; especially when the object in view is to preserve the steel pinions, which carry the brass wheels of watch movements, and which must be subjected by the effect of graining to friction, which it is necessary that this varnish should resist, seeing that it cannot be preserved from it. One of the best varnishes consists of a mixture of 3 parts of rosin, with 1 part of yellow wax, 1 of red oxide of iron, and 2 or 3 of betuline, a resinous substance that is obtained by treating the bark of the birch by alcohol, and which possesses the advantage of not being soluble in alkalies.* The application of these varnishes likewise permits of the production

* There exist different processes for covering the steel pinions with protecting varnish — an operation which is termed *stopping out* the pinions. It is necessary, first, to wash the entire wheel with alcohol, in order to remove fatty bodies; then, after having stopped out the pinions, the piece is cleansed, dried in saw-dust, and dotted on a cork; it is then grained and scratch-brushed. This being done, it is gilt, the *stopping* is dissolved (this is the name given to the varnish with which the pinion is covered) in hot olive oil; the gilding is scratch-brushed; and, finally, the piece is washed in alcohol, and is wiped with a fine cloth.

upon the same article of gildings of different colours, and even of applying, at pleasure, gold and silver upon fixed places, in the dead or the brilliant state, and thus to construct charming works in plating.

Among the applications of electric gilding, there is one, devised by M. Hammann, a distinguished artist of Geneva, which has given satisfactory results. It consists in substituting a very thin film of gold, deposited upon the copper-plate by the electric current, for the ordinary engraver's varnish in engraving by aquafortis. This film does not present greater resistance for working with the point than does the varnish; and it is, besides, sufficiently powerful to resist the mordant, which, as we know, is diluted nitric acid.

We shall not terminate this Section without saying a few words upon the trials that have been made, for applying to the arts M. Nobili's discovery of the coloured deposits obtained at the positive electrode by the decomposition of acetate of lead. M. Becquerel has extended and perfected this process, which rests upon the same principles as that of gilding, and the application of metals by the electric way, with the sole difference, that here it is oxides, and not reduced metals, that are deposited upon the surfaces that we are desirous of covering. It is principally the peroxides of iron and lead that M. Becquerel has succeeded in depositing in thin adhering films, not only upon gold, platinum, and silver, but, which is much more essential, upon copper, iron, and other metals in common use, in order to preserve them from atmospheric influences. In order to produce these deposits, it is necessary that the peroxide be dissolved in alkalies; namely, the peroxide of lead in potash, and the peroxide of iron in ammonia. With the former solution, we obtain, upon a plate of iron or copper, serving as positive electrode, a deposit of a colour of black lead on iron, and jet-black on copper, which is susceptible of acquiring a beautiful polish, remaining very adherent. With the second solution, the colour of the deposit is brown-red provided that the plate remains a short time immersed; but

if the current passes for a longer time, the deposited film assumes a deeper and deeper tint, which finishes by becoming violet. The only object of these deposits, on account of the unalterability of the oxide, of which they are formed, is to preserve the metallic surfaces, which they cover, from all alteration on the part of atmospheric agents. But if the object in view is ornamentation, it is necessary to employ the deposit of peroxide of lead in very thin films, which enables us to obtain coloured tints as remarkable by their variety, as by their brilliancy. In order that this brilliancy may be as great as possible, it is necessary that the surface, intended for receiving the deposit, should be polished in the best manner, by being rubbed with leather and jewellers' rouge, which brings about the reflection of a greater quantity of light, and consequently heightens the vivacity of the colours, produced by the play of light in these thin films. These deposits can be only obtained upon gold or silver, or upon metals strongly gilt or plated; seeing that, as the metal must be plunged into the solution as positive electrode, it would be attacked if it were of an oxidisable nature; and then, its surface being altered, the films of peroxide would no longer be deposited upon it, so as to produce the desired effects.

In order to cover metallic surfaces with a deposit of peroxide of lead, that presents tints as vivid as those of Newton's thin plates, the object A B, whose surface is to be coloured, is attached to the positive pole of a Bunsen's battery of two or three pairs; it is plunged into the vessel A B (*fig.* 426.), containing the solution of peroxide of lead in potash; a platinum wire C, communicating with the negative pole of the battery, is then taken in the hand, and it is moved about in the liquid, at a certain distance from the plate. The deposit immediately commences, and presents the successive colours of thin films. If the wire is very near to the middle of the

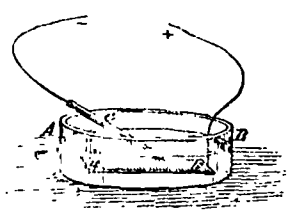

Fig. 426.

plate, there is formed upon the surface a series of coloured rings of very vivid shades, which is due to the circumstance that the deposit has a variable thickness from the centre to the circumference. It was rings of this kind that Nobili had obtained; but, if the wire is held a little further from the plate, the latter is coloured in a manner that is very nearly uniform; only, the colours change with the duration of the operation, that is to say, with the thickness of the transparent thin film; and they succeed each other precisely in the same order as in the coloured rings seen by transmission, as M. E. Becquerel has observed. If, in the operation, we have passed beyond the point necessary for producing the film of the desired colour, or if the deposit is not suitable, we have merely to wash the plate in a dilute solution of acetic acid in order to make it totally disappear, and the surface is as clean as before the operation, and ready to receive a fresh film of the peroxide. On the other hand, when the operation has succeeded, it is necessary to be careful, after it is completed, to wash it in abundance of water, in order to remove the potash, which, but for this, would react upon the peroxide and decompose it.

We can easily conceive that this mode of colouration can only serve for small objects, if we desire the tint to be uniform; also, when we desire to produce objects of ornament of different shades, we take the precaution of acting upon the articles separately, to each of which a uniform tint is given, and which are then all mounted together. However, we may give different colours to the various parts of a same object, by covering with a varnish such of the parts as are not to receive the same colour, whilst the others are receiving the deposit. Thus, suppose we have to colour with different colours a group of flowers, chased and engraved upon a plate of metal, the following is the mode of proceeding:—If the plate is not of gold, we shall commence by gilding it strongly, after having well deadened it; it is upon this dead and gold ground that the colouration is brought about. The ground, and all that is to remain of the colour of gold, is covered with a black liquid varnish, or

stopping *, by means of a small pencil; the operation will then be commenced. When all the flowers have the clear red colour, which is the first that shows itself, those which are to remain of this colour must be covered with stopping, the remainder are then led on to violet; those which are to remain violet must be covered with stopping, and the remainder are to continue being put forward in colour as far as blue, which is likewise to be covered with stopping; finally, nothing remains uncovered besides the leaves. The colouration is then extended as far as green, which may still be shaded, since the first green that shows itself is deep, which, if the operation is prolonged a moment longer, becomes clearer, and ends by becoming yellow. When the article is thus coloured, the varnish is dissolved in essence of turpentine, cold; it is washed with a brush in soap and water, then again with warm water, and is wiped with a fine cloth. These various colours, which imitate the natural colours of flowers, and which are placed upon a dead gold or silver ground, present a very beautiful appearance. We can, besides, understand that we are able greatly to vary the colours, and instead of flowers, to paint birds and other objects. For example, this process has been applied to the colouring of the hands and screws of watches, and they have been coloured red, so as to produce a very beautiful effect. It is only necessary to pay attention, that, as the colours appear less deep in the bath than they are in reality, the objects must be removed from the bath before they have attained apparently the colours desired. The only inconvenience that is presented by this mode of colouration, by means of the electro-chemical deposits of peroxide, is its susceptibility of altering, either by the contact of the moist hands, or by simple prolonged exposure to the air. It is therefore necessary

* The following is the composition of this stopping, which may be employed in many cases:—

Very siccative copal varnish - - -	9 parts.
Lamp-black - - - - -	1 „
	10

This composition is dissolved in essence of turpentine, which is heated with caution.

to place the objects thus coloured under glass. What would be best, would be to cover them with a varnish, as colourless as possible, that might be without action upon the peroxide of lead; but it does not appear that we have yet succeeded in finding a varnish, the application of which leaves the colours perfectly intact.

Application to Galvano-Plastics.

As much as it is important in gilding, and in the application of metals upon each other, that the deposits be adherent, just so much is it indispensable in galvano-plastics, that they have little adhesion. The object of galvano-plastics is to obtain, by means of a metallic deposit, which is produced upon a mould in intaglio or in relief, serving as negative electrode in a metallic solution, the impression of the surface of this mould. We can therefore understand how important it is that the deposit may be detached easily, and without breaking. We shall see, in a moment, how this object may be attained; but let us first say a few words upon the discovery itself of galvano-plastics [electro-type].

Two philosophers may equally claim it as belonging to them, Mr. Spencer in England, and M. Jacobi in Russia. It is by decomposing sulphate of copper, and collecting the copper at the negative electrode, that the two philosophers observed that the molecules of this metal aggregated powerfully together, and took the impression of all the hollows and reliefs that are found upon the surface of the electrode. Each of them succeeded in producing, in intaglio, coins, medals, and other objects in relief; they both recognised that, in order that the deposit may combine all the necessary conditions of homogeneity and solidity, it was always necessary to operate with a saturated solution of sulphate of copper. Mr. Spencer did not confine himself to moulding in intaglio objects in relief, but he also made use of the moulds themselves for obtaining impressions which were the *fac-similes* of the objects, and he applied his process to the reproduction of typographical characters, engraved copper plates, &c. M. Jacobi, while still devoting himself to the same class of

applications, devised several improvements in the mode of operation. He conceived the idea of employing a battery of one or of several pairs for decomposing the sulphate, taking as a positive electrode a plate of the same nature as the metal in solution, copper with sulphate of copper, so as to replace by the metal dissolved at the positive electrode, the equivalent portion that disappears from the solution.* Mr. Spencer and M. Jacobi at first employed only a simple apparatus, in which the mould was the negative element of a pair, of which a plate of zinc, placed in communication with the mould, was the positive element.

The preparation of the mould is one of the important points of galvano-plastics; it is, in the first place, necessary that its surface should be conducteous, and may be easily placed in communication with the negative pole of a battery; when the mould is not of itself made of a conducting substance, it is necessary to cover its surface with an infinitely thin film that is so. For this purpose, we make use of either an impalpable metallic powder, such as that of silver, or very finely divided black-lead powder: this latter powder is applied with a pencil, with rather long hairs, impregnated with plumbago; a second, finer and softer pencil, is employed for removing the excess of plumbago, and for giving a brilliant polish to all the parts of the mould. Sometimes the operation is commenced by impregnating the non-conducting mould with a solution of nitrate of silver, or any other salt of silver, gold, or platinum that is reduced by the vapours of phosphorus; which brings about a continuous thin film of silver. Finally in certain cases, a thin sheet of gold, or of any other metal which metallizes it, is applied by pressure against the mould. Non-conducting metallized moulds generally allow the moulded object to be liberated very easily; but when they are themselves of metal, the adherence is sometimes so powerful, that there is a risk of breaking the object in detaching it. Mr. Spencer had remarked that, in order to avoid adherence, it is necessary to wash the surface, when it is well

* We know that the equivalent is never perfect, which is due to causes that we have already analysed (Vol. II. p. 380.).

polished, with a feeble alkaline solution, whilst, in order to obtain a strong adherence, it is necessary to cleanse it, as we have seen in the preceding paragraph, with an acid. We may likewise secure ourselves against adherence, by exposing the surface of the metallic mould to the vapour of iodine, as it is employed for preparing a daguerreotype impression, until it has acquired a yellowish tint. It is even sufficient, for avoiding adherence, to leave the mould for some time exposed to the air, which produces upon its surface either a slight film of oxide, or a simple film of air adhering, which, being interposed between the mould and the object moulded, permits of our detaching the latter more easily. Besides, with a little skill, we soon succeed in preventing adherence, which enables us to produce deposits upon moulds that are entirely metallic, a condition eminently favourable for the success of the operation, which always succeeds better thus than with non-metallic moulds.

With regard to the manner of making moulds, if we desire them in metal, we make use of lead, or of the various fusible alloys, that are furnished by chemistry; and when the one that we have selected is in the state of fusion, the object whose impression we desire to obtain is applied upon the surface with pressure, until the alloy has become solidified. We are likewise able with a press easily to procure impressions of medals upon sheet lead, the surface of which is well cleaned. If non-metallic moulds are the object in view, it is necessary to make them of plastic substances, which react neither upon the solution nor upon the precipitated metal. Ordinary sealing-wax, also virgin wax, receive impressions in a very perfect manner; a mixture is also employed of equal parts of yellow wax and resin, which requires only a very slight elevation of temperature in order to serve as a mould. When plaster is employed, certain precautions are necessary; it is necessary to free it from all the air that may be mixed with it, and to cover it with a film of siccative linseed or neat oil, which is heated to ebullition, in order that it may dry promptly; which renders the mould impermeable to the sulphate of copper. Moulds are also prepared with stearine; but

when it is pure it is not sufficiently pliable, and runs the risk of cracking; so that, in order to render it fit for the use in question, it is good to add to it one or two-tenths of wax.*

Finally, successful attempts have been made in many cases to employ gutta percha for making moulds, either by simple pressure or by fusion, mixing it, in order to make it melt, with one-half of its weight of linseed oil. We may add, that sulphur would be an excellent material for obtaining delicate impressions, if it did not present the inconvenience of exerting an action upon the precipitated metal.

When once the mould is prepared, it is necessary, if it is of metal, to solder to it a conductor, which may place it in communication with the battery; and, if it is not a conductor, it is necessary, after having metallized it, as we have pointed out, to surround it on its whole circumference with a ring or wire of copper, which presses upon it strongly, and from which a conducting wire comes out, which leads to the battery. Only it is necessary to take great care to extend the conducting film, which has served to metallize the mould, as far as to the copper circle, in order that the electric current may penetrate into this film by all the points of its circumference.

* When we desire to obtain a mould in plaster or in stearine, we commence by surrounding the medal or the object, whatever it may be, the mould of which we desire to obtain, with a very thin band of card, or with a little ribbon of metal, which forms around the object that is to be reproduced a rim more or less elevated, according to the height of the reliefs that the original presents. If plaster is the object in view, it is taken as fine as possible, and is dissolved in water in order to make of it a clear thin paste, with which the bottom of the mould is covered with a pencil, so as to penetrate into all the hollows of the model; upon this first layer of plaster, which is about a twelfth of an inch in thickness, the tempered plaster is gently poured, until the total layer possesses the desired thickness. The mould is slightly tapped upon a table, care being taken to keep it horizontal in order to cause the escape of the bubbles of air, that might have been able to remain in the hollows of the model. We wait till the plaster is set, in order to separate the mould. We operate in the same manner for stearine moulds; the melted substance is poured upon the medal, which has been previously heated, in order to prevent this substance from setting immediately on contact with the mould. We must likewise expel bubbles of air with a pencil, or by slight shocks, as for plaster. It is necessary, before this operation, to take the precaution of previously coating the surface of the mould with a slight film of soap by means of a pencil when plaster is the matter in hand, and of olive oil when wax or stearine is in view. When the model of which we desire to take the impression in wax or stearine is of plaster, it is necessary to take the precaution of keeping it moistened with tepid water before pouring on, and while pouring on the melted composition.

All these preliminary operations being finished, the question then is, to bring about the deposit of copper. We may employ, as we have said, for this purpose, a simple apparatus and a compound apparatus. The simple apparatus (*fig.* 427.) is composed of a glass vessel, A B, in which is the saturated solution of copper, slightly acidulated. A wide glass tube, C D, closed at its lower part by a diaphragm of bladder, *a b*, is placed in the vessel, so as to plunge only into the upper stratum of the sulphate. It is held by means of a small wooden plank, E F, pierced with a central opening a little smaller than the section of the cylinder, and which is retained by the aid of hooks of copper wire, which are fixed upon the edges of the outer vessel A B. We may with advantage do without this plank, by confining ourselves to fixing the interior tube to the outer jar, by means of attached pieces coming from the former, which, in this case, is at the same level as the top of the vessel. Water, acidulated with sulphuric acid, is placed in the cylinder C D; a disk of amalgamated zinc is plunged into it, from the centre of which comes a thick copper wire, T, which is held fixed by means of a glass rod, G H, which rests upon the edges of the vessel, and around which a turn of wire is passed. The object to be reproduced, or the mould, is placed at the bottom of the vessel; but it is necessary to take care that the face, upon which the copper is to be deposited, is quite horizontal and turned upward. The conducting wire that comes from the object is attached to the wire G; and, the circuit being thus closed, the decomposition of the sulphate of copper takes place. In proportion as it is brought about, the solution becomes weaker; but, in order to maintain it at the same degree of concentration, crystals of sulphate of copper are placed upon the wooden slab E F, which are dissolved in proportion as the liquid is exhausted. This precaution is

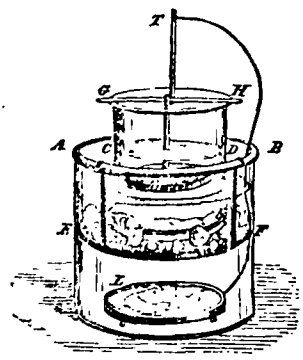

Fig. 427.

important; for, in order to obtain a compact and adherent deposit of copper, it is necessary that the sulphate should be very concentrated; for then it is the salt itself that is decomposed, and not the acidulated water; which, on the contrary is decomposed when the concentration is less. Now, as we have seen*, the deposit of copper that results from the reduction of copper by the action of the nascent hydrogen of the electrolysis of water, is granulous, and consequently defective; whilst that which arises from the direct electrolysis of the sulphate is ductile and brilliant. Neither must the operation be conducted too rapidly; for in this case the copper would be brittle. Experiment easily indicates the degree to which the water must be acidulated, in order to obtain a current of the suitable strength; water containing $\frac{1}{20}$ of sulphuric acid is in general that which suits best. Finally, care must be taken to cover with an insulating varnish the wires or copper plate with which the mould is surrounded, when it is made of a non-conducting substance, in order to preserve them from a deposit of copper. A plate of lead, which can be more easily detached, is advantageously substituted for the copper plate; and, in order that the rim of copper, which is formed upon these plates, may not oppose the separation of the deposit and the mould, care is taken to give them greater width, in order that they may extend a twentieth of an inch, beyond the surface of the mould.

Porous diaphragms are sometimes employed in the simple

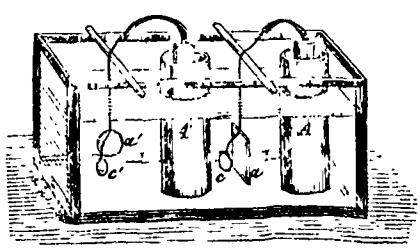

Fig. 428.

apparatus. Thus, in a trough filled with sulphate of copper, porous vessels A and A′ are plunged (*fig.* 428.), so that the

* Vol. II. p. 386.

solution of sulphate is half an inch or more below the top of these vessels. In their interior is introduced acidulated water, then a cylinder of zinc, furnished with a rod of copper, that is placed in communication with the conducting wire, that comes from the objects *a* and *a'*, upon which the copper is to be deposited, and the surface of which, that is turned on the side of the porous vessel, is the only one that is conducteous. If the object is metallic, care must be taken to cover the other face with an insulating varnish. The precaution must be taken, when gutta percha moulds are employed, or moulds of any other material that is not very heavy, to adapt to them, in order that they may plunge well into the middle of the solution, counterpoises, *c* and *c'*, of copper, covered with varnish, which causes the copper not to be deposited upon it. This arrangement possesses the advantage of enabling us to place in the same solution several simple apparatuses; but it possesses, on the other hand, the inconvenience of compelling us to place the moulds vertically, which prevents the deposit being as homogeneous and uniform as when they are horizontal. There are then produced streaks and inequalities of thickness, which are due to vertical currents, that are established in the liquid when its density varies, as is the case here, in proportion as the decomposition is brought about.

The simple apparatus possess one inconvenience: it is the endosmose that is necessarily produced through the diaphragm which separates the acidulated solution from the solution of sulphate of copper. The result of this, at the end of a certain time, is the presence in this solution of a little sulphate of zinc, which compels us to renew it; a small inconvenience, it is true, by the side of the advantages and the simplicity of this kind of apparatus. The compound apparatus do not possess this inconvenience, since the production of the electricity takes place outside the solution of sulphate of copper, which is decomposed. In this case, we are able to employ a copper positive electrode, which is termed a soluble electrode; because, as we have said, it is dissolved in proportion as the sulphate of copper is decomposed, so as to

replace in the solution the copper deposited upon the negative electrode. This solution is placed in a vessel, A B (*fig.* 429.), in which is plunged the article D, upon which

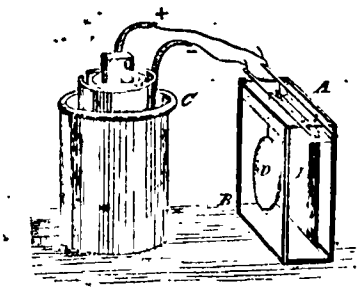

Fig. 429.

copper is to be deposited, and which communicates with the negative pole of a pair, C, the positive pole of which leads to a copper plate, L, which is dissolved. Instead of one pair, several may be arranged in series; this depends upon the size and the nature of the deposits that are desired to be produced. When the object in view is to produce medals, or subjects of the same kind, a single pair is sufficient. If we desire it, the mould may be placed horizontally, in order to avoid the inconveniences of the vertical arrangement; but, in the very numerous cases in which this is not necessary, several deposits may be produced at the same time, by placing a large plate of copper, L L, in a trough, filled with sulphate of copper (*fig.* 430.), which plate occupies the

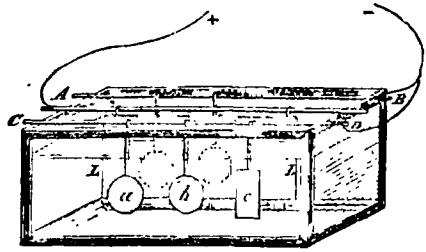

Fig. 430.

middle of the trough, and communicates with the positive pole of the battery, whilst on each side of it are suspended

from two brass rods, in connection with the negative pole, prepared moulds, *a*, *b*, *c*.

We may also add that the beauty of the deposit depends, not only, as we have seen, upon the intensity of the current, and on the degree of concentration of the solution, but upon the purity of the sulphate of copper, which must be selected free from sulphate of iron, which is sometimes found mixed with it. When the sulphate is in beautiful crystals, we may be sure of its purity. Other salts may be employed, and among them the nitrate and the acetate; but, whether on account of its lower price, or on account of the facility of its manipulation, the sulphate is generally preferred.

We shall not dwell upon the attempts, that have been made, to deposit other metals besides copper by galvano-plastics. These attempts, in general, have not been very successful. Gold and silver have, however, presented good results. For gold, the same solutions are employed as for gilding; it follows, of course, that compound apparatus must be employed, and a plate of gold must be taken as a positive electrode. With regard to silver, the double cyanide solution of potassium and silver employed in plating, has been likewise used with advantage; the saturated solution of the sulphate, as well as that of the nitrate has been likewise employed; but, with this latter solution, it is necessary that the current be very weak. It is necessary, when the galvano-plastic is made of silver, to metallize the moulds with silver powder instead of employing plumbago.

As we have said, it is the galvano-plastics of copper that has chiefly taken rank in the industrial arts, and which has furnished numerous applications of the greatest interest, which we are about to run over rapidly. We shall only previously insist upon the facility and the delicacy with which the well managed deposit of copper reproduces, even to its smallest details, all the parts of a mould; and if, instead of depositing metal upon a mould, it is received upon a plate of metal, silver for example, extremely well polished, a plate of copper is obtained, the surface of which, in contact with that of the silver, possesses such a polish, that it would be impossible to obtain one so perfect by the ordinary me-

chanical means. Advantage has been taken of this property for fabricating the silver plate, that is used for daguerreotype pictures. M. Belfield, who has conceived this idea, commences by depositing, by the electro-chemical way, upon a perfectly polished plate of brass, a layer of silver, pure, homogeneous, and uniform, the thickness of which is varied at pleasure. Then, upon this layer of silver, he precipitates another of copper. When the latter has acquired a thickness sufficient to present a suitable resistance, the double plate is detached from the brass plate upon which it has been formed—a delicate operation, and for which great care is necessary. A plate of copper is thus obtained, covered with a layer of silver, perfectly polished, and fit for daguerreotype. This process does not appear to answer, whether in respect to economy, or on account of the difficulties of execution, for the fabrication of plates in general.

The principal application of galvano-plastics is undoubtedly the reproduction of medals, as well as that of bas-reliefs, busts, statues, and all the objects of art of the sculptor and of the founder. We have already explained in detail the manner of obtaining this reproduction, when medals are the objects in view, by operating either upon the medal itself, which, serving as a negative electrode, gives in intaglio a model which is again placed in operation, in order to obtain the image in relief; or, if we fear to damage the model, we operate upon the impression of the medal taken by the methods and with the precautions, that we have pointed out. Specimens are thus obtained of the medal so perfect, that it is often a difficult matter to distinguish them from the original. They may besides be bronzed, plated, or gilt, according to the processes pointed out. When the object in view is the reproduction of a subject of sculpture, it is rarely that it can be obtained in a single piece, except in the case of a statuette of very small dimensions. In general, moulds in intaglio are taken of the different parts of the model; they are then covered interiorly with plumbago, and are connected together with wax or plaster, rendered impermeable, so as to form a kind of hollow vessel fit for receiving the solution. In this case, a powerful battery and

a solution not much concentrated must be employed, in order that the current may be distributed equally throughout; and, for this same reason, as great an extent as possible must be given to the piece of copper, that serves as positive electrode.

When we have obtained the various galvano-plastic pieces of the model, it is necessary to solder them together, which may be done by making a soldering with silver or tin, which is afterwards covered with a layer of copper. It is this method that we have been compelled to employ for connecting together the two faces of a medal, which naturally can only be produced separately. Galvano-plastics, when employed for the reproduction of objects of sculpture of considerable dimensions, requires the co-operation of the founder's art, both in order to accomplish properly the union of the pieces, as well as for the fabrication of certain parts, which galvano-plastics is powerless to produce in a suitable manner. Upon this basis it is, that the great establishment of the Duke of Leuchtenberg has been founded at St. Petersburg, in which it was proposed to reproduce colossal statues. Although the object that had been in view has been attained, it appears, however, that the results have not been so satisfactory as had been hoped for. The high price of this mode of fabrication, when it is carried on upon a large scale, has been one of the principal causes that have led to its being abandoned; but, more than this, it would appear that the products of galvano-plastics are not capable of withstanding the injuries of time anything like so well as those of the founder, which is probably due to the circumstance that the aggregation of the particles of copper is not so well accomplished in the cold as by heat. However, galvano-plastics has already reproduced a very great number of *chefs-d'œuvres* of statuary and sculpture, busts, full length statues of the natural size, and even more than ten feet in height, a host of bas-reliefs, and other sculptured objects, which were the objects of admiration in the Universal Exposition of 1855; but it appears to me a difficult matter for it to take the place of the art of the founder for large artistic

monuments intended to be displayed in the open air. These various objects are of copper, although bas-reliefs have been made in silver; but we are able, which amounts to the same thing in appearance, and is much more economical*, to cover the works of copper, by means of the battery, with a plate of silver, which succeeds extremely well. When it is preferred to leave the copper bare, it is proper, in many cases, to give to it a bronze colour, which in general produces a better effect than the colour of the copper reduced by the battery.

Bronzing is produced in various ways, the most simple of which consists in rubbing the copper with plumbago; then it is placed upon the fire in order to heat it slightly. A very weak solution of ammonia, or of sulphate of potash, gives also to copper a beautiful bronze colour. We succeed in obtaining a very beautiful tint of Florentine bronze, by simply heating the copper object, for instance a medal, to a certain temperature; only, care must be taken that the heating shall be accomplished equally on all the points, in order that the oxidation, which is the cause of the phenomenon, may be uniform upon the whole of the surface.

In the same manner as medals are reproduced we are able with galvano-plastics to reproduce watch faces, more or less chased or ornamented. For this purpose, it is necessary to employ a model face, which it is preferable to have in gold or in silver; because these are the metals upon which the most beautiful engine-turning is obtained without shade, and which cut best under the tool of the engraver; we are likewise able to fabricate in this manner the backs of watch-cases. We should be unable, without trespassing beyond

* M. Figuier, in his interesting work *Upon Scientific Discoveries*, remarks with justice that, in the interest of art, and of the preservation of the beautiful works that are due to it, it is far preferable that the material employed shall not be of too high a price. The artist is thus able to multiply to a much greater extent the products of his imagination, not being restrained by the great expense, which results to him from the employment of the precious metals, silver, for example; and, on the other hand, the *chefs-d'œuvre* will not run any risk of being reduced into ingots, as too frequently happens in the time of revolutions. Thus, it is remarked, that all the sculptured works executed in bronze in the last two centuries have been preserved to us, whilst those in silver, of which there was a very great number, have almost totally disappeared.

due bounds, to enumerate all the forms of application that galvano-plastics presents; but, if we are unable to enter into all these details, we may be allowed to quote M. Boquillon, as being one of the persons, who has most contributed to perfect this new art by the various practical processes that he has devised.

Instead of reproducing, by means of a mould, the objects of art, we may simply desire to cover them with a layer of copper, in order to impart to them a massive appearance, and to enable them to resist the action of the air and moisture. Such, for example, is the case for small statuettes and other works modelled in plaster; we must commence by rendering their surface conducteous by the aid of plumbago, or of a metallic powder; they are then plunged into one of the apparatus that we have described. In order to obtain the thickness of the deposit uniform, which is essential for preserving to the different parts of the object in relief their relative proportions, we must endeavour to give to the copper plate, that is used as the positive electrode, a form as analogous as possible to that which a cast taken from the model would present. Various other precautions are necessary when the object is of considerable dimensions; as, for example, to proceed by successive operations, by covering with an insulating varnish the parts, wherever the thickness of the layer of copper is sufficient, in order to increase this thickness in the other parts. When the object is to cover insects and fruits with copper, we have merely to cover them with plumbago, and to thrust a pin into some part, which serves to establish communication with the negative pole of the battery.

One of the most important and the most elegant applications of galvano-plastics is that which concerns what may be called electro-type; that is to say, the reproduction of plates intended for engraving or printing. Mr. Spencer, as we have said, has been much occupied on this subject; and the perfect identity of the impressions thus obtained with the models, to such a point that the most delicate lines, even those which are visible to the microscope alone, were repro-

duced, had led to the supposition that this process would be valuable for the reproduction of engraved plates of copper and of steel. The design engraved being in intaglio, we must commence by obtaining a mould in relief, with which we procure a mould in intaglio, similar to the original. In order to avoid, which is a very difficult matter, adherence between the original and the mould in relief, various methods may be employed, such as covering its surface with a thin pellicle of a fat body or of wax, by rubbing it when warm with these bodies,—such as placing the plate in an open place for four and twenty hours, which brings about the formation of a film of air, sufficiently firm to prevent adhesion. Mr. Mathiot of the United States has proposed to employ the vapour of iodine, the efficacy of which we have already seen in this case; but then, in order that its effect may be uniform, and may be exerted equally upon all the parts of the engraved plate, we must commence by silvering the latter. In order to prepare his larger plates of ten square feet of surface, Mr. Mathiot employs the solution of 1 grain of iodine in 20,000 grains of concentrated alcohol. The delicacy of the lines upon the plate is so little diminished by the employment of this chemical method of preventing adherence, that Mr. Mathiot has been able to electro-type seven times successively, in relief and in intaglio, a same engraved plate, without his having been able to perceive the least difference between the last reproduction and the original. The large charts of the coasts of America have been reproduced by this electrotype process. It is necessary in these operations to take the precaution of placing the plates horizontally, and of operating slowly, in order to obtain a deposit of copper sufficiently compact and hard. If the plates are of steel, since they cannot be plunged into any of the solutions of copper without being attacked, the first impression must be obtained in silver, and we are then able to obtain the counter-impression in copper; but the result of this mode of operating is not always satisfactory.

Although the reproduction of a plate by the direct deposit of copper is the method that appears to give the best results,

however, there are cases, and in particular when steel plates are in question, in which it is preferable to procure a mould, by taking the impression of the engraved plate with wax or gutta percha, or better still, with a plate of lead well cleaned. With this view, this plate is placed in a copper-plate press beneath the engraved plate; and it is covered with a plate of iron.

We are likewise able to reproduce plates engraved on wood; and for this purpose we commence by taking a copy in intaglio, by covering the upper surface of the plate with a coat of plumbago, and its lower surface, as well as its sides, with wax or fat, in order to prevent absorption. This process is valuable for multiplying in copper the engravings upon wood comprising vignettes and various ornaments employed in printing, which are known under the name of *clichés*.

All the processes that we have been describing, and other analogous ones besides, upon which it would be useless to dwell, consist in depositing copper galvano-plastically, either upon plates engraved in intaglio, in order to obtain counter-impressions in relief, upon which a second deposit is produced, which gives a plate similar to the original; or else directly upon moulds in relief, prepared by the methods indicated.

It remains for us to speak of certain modes of reproduction of designs, that give beautiful results. Thus, the Duke of Leuchtenberg has conceived the idea of substituting for the printing ink with which the copper-plate is covered from which we desire to obtain an impression, a mixture of resin of Damara, red oxide of iron, and essence of turpentine, and with which an impression is pulled on very thin paper. This impression, while still fresh, is applied upon a polished plate of copper or of silver, so that the design touches the plate; and, after desiccation, the paper is removed by means of water, so as to leave only the design, marked in ink upon the surface of the copper. On reproducing this plate, by means of the electrotype process, a plate in intaglio is obtained fit for working from in the copper-plate press.

Upon a similar principle depends the most remarkable

unquestionably of the electrotype processes, to which M. de Kobell of Munich, its inventor, has given the name of *galvanography*. The drawing that is required to be reproduced is washed in upon a plate of silvered copper with a single colour, such as ink that is not very thick; or better still, with an encaustic colour, prepared by means of a solution of wax in essence of turpentine, or in balm of copaiba.* We may also employ simply a colour composed with lithographic crayon of the hardest kind, pulverised and tempered in distilled water. Deep tones are given by greater thicknesses of colours, demi-tints by mean thicknesses, and lights by the absence of all colour; thus it is that the drawings are formed. Without dwelling upon the various details relative to the manner of improving the drawing, so as to obtain lights and shadows, as well as their various shades, we will confine ourselves to adding that it is upon this drawing that a layer of copper is deposited by galvano-plastics, of sufficient thickness to form a plate capable of resisting pressure, presenting in intaglio all the marks from the deepest to the finest, which renders it fit to be employed as an engraved plate.

We may also, instead of making a drawing upon a plate of copper, apply to it mechanically the object itself that we desire to reproduce, after having taken the precaution of soaking it with a mixture of turpentine and spirits of wine, in order to fix it, and to spread it better upon the plate. Above it is placed a plate of pure lead, well cleaned, and the whole is pressed; this body leaves an impression in intaglio upon the lead. Upon this plate is then deposited, by the galvano-plastic way, a plate of copper, which produces in relief the object pressed; and, if a second deposit is made upon this plate, we obtain a copper-plate in intaglio fit for giving on printing a proof of the object. It was by this process that MM. Auer and Worring at Vienna reproduced with striking accuracy and truth objects of every kind,—

* M. de Kobell also employed with success a colour composed of essence of turpentine, holding in solution resin of Damara, coloured with peroxide of iron

lace, embroidery, flowers, leaves of trees, entire plants, fossils, insects, &c. All these objects are reproduced, with their colours and their natural relief, or simply in black. Great skill is necessary in order to ink the plates well, when the object is to print them in various colours. The first copper-plate that is obtained, and which is in relief, may be used without having need to have recourse to the counter-proof in intaglio. Only, in order to print it, the colour is deposited by means of an inking-roller, instead of rubbing it into the depths, as is practised for engraving in intaglio.

The accuracy and the delicacy with which the galvano-plastic layer reproduces the smallest details of the plates upon which it is deposited, have made M. Fizeau think that an engraving might be obtained of daguerreotype impressions, by depositing copper upon the surface of the plate upon which the image is situated. We find, in fact, upon the copper an image similar to that of the original, but symmetrical, as if it were seen in a mirror. This effect is due to the circumstance that, on the daguerrean plate, the shades are formed by the polished parts of the plate, and the lights by the dead parts; now, the surface of the galvano-plastic plate is also found polished where it corresponds to the polish of the daguerrean plate, and dead where this plate is dead. Only, in order to avoid the adherence of the copper to the daguerrean plate, it is necessary to fix with chloride of gold the positive image that is deposited upon the plate. This process, which is equivalent to the deposit of an infinitely thin film of gold upon the daguerrean picture, enables us to plunge this latter with impunity into the sulphate of copper bath.

Mr. Grove has endeavoured to transform in a direct manner the daguerreotype plates into engraved plates; but then it is no longer by depositing on their surface a layer of galvano-plastic copper, but, on the contrary, by placing the daguerrean plate at the positive pole of a voltaic pile in solutions which attack the silver and not the mercury. After a great many trials, made conjointly with Mr. Gassiot, Mr. Grove found that the best solution was a mixture of one volume of distilled water, and two volumes of hydrochloric

acid. These two philosophers place the plate in a trough filled with this acid, plunging into it parallelly a plate of platinum of the same dimensions, which serves as a negative electrode, which they have taken care to platinise in order to prevent the hydrogen adhering upon any point whatever of its surface, which would cause the corresponding part of the daguerrean plate to undergo a less amount of action. It is necessary to take the precaution of varnishing with a solution of gum-lac the back and the edges of the daguerrean plate. When the plate has been removed, and has been washed with distilled water, we find that it presents a beautiful design, of the colour of terra sienna, of the original image; an effect which is due to the chlorine that is liberated on its surface attacking the parts of this plate where the silver is bare, and producing a sub-chloride of a deep colour. In order to make it disappear, the plate is plunged into a very weak solution of ammonia, and its surface is gently rubbed with very soft cotton, until the deposit is dissolved; it is then washed and carefully dried. We then have a plate, which represents the perfect engraving of the original design, and which gives, consequently, a positive image. Only, many precautions are necessary, in order to obtain a good impression, if we desire to obtain an engraving sufficiently deep, and which, however, shall not be sufficiently so for the lines to encroach upon each other, which would detract from the beauty of the images. It was only by long experience, and after several trials, that Messrs. Grove and Gassiot succeeded in determining the quantity and intensity of the current, the distance between the two plates serving as electrodes, and, finally, the duration of the operation most fitted for insuring the success of the result. One Grove's pair as a source of electricity, with about a fifth of an inch of distance between the two plates, and 25 to 30 seconds for the duration of the operation, with liberty to plunge the plate in again, if this time has not been sufficient; these are the data that result from the researches of the two philosophers. We may add, that the plates thus engraved are of such delicacy, that they resist with difficulty the action of the press, which

causes the number of impressions that can be pulled from them to be very limited.

Mr. Smee has also conceived the idea of placing at the positive pole of a battery, formed of one or two pairs, and of plunging in a solution of sulphate of copper, a copper plate covered with a coat of varnish intended for engraving by aquafortis; substituting thus the action of the oxygen and acid liberated at its surface, for that of diluted nitric acid upon the copper exposed by the fine point. Care must be taken that the plate which serves as negative electrode shall not be greater than the positive. With certain precautions we are able to produce, by this mode of engraving, lines of greater or less depth, which causes us to obtain very easily gradations from light to shade. Mr. Walker has devoted much attention to questions relating to galvanography, and he has introduced several improvements in detail. In order to obtain a good engraving, a process has been devised of placing upon a copper plate, previously immersed in diluted nitric acid, an impression still fresh from an engraved plate; the transport of the ink from the impression to the copper plate is brought about by means of the press. This plate is then slightly gilt by the electric current; the gold is not deposited upon the parts covered with ink, but only upon the copper; it is then washed with essence of turpentine, which dissolves the fatty ink, and exposes the copper in all the points that were covered by this ink. The plate thus prepared is then placed in sulphate of copper, being made to communicate with the positive pole; and, in this manner, an excellent engraving is obtained.

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Bucholz. — Idem. *Ann. de Chim.* t. lxvi. p. 226.
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Matthiessen. — Idem. *Ann. de Chim. et de Phys.* (N. S.) t. xlv. p. 347.
Deville. — Preparation of Aluminium. *Ann. de Chim. et de Phys.* (N. S.) t. xliii. p. 33., and t. xlvi. p. 415.
Davy. — Preservation of the Sheathing of Vessels. *Ann. de Chim. et de Phys.* t. xxvi. p. 84.; t. xxix. p. 187.

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De la Rive. — New Process of Gilding. *Ann. de Chim. et de Phys*, t. lxxiii. p. 398.; and *Bibl. Univ.* (1840), t. xiii.; *Arch. de l'Electricité*, t. i. p. 615.

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Becquerel. — Treatment of Ores by the Electro-chemical way; Gilding and Application of Metals; Application of Oxides; Colouration of Metals. *Ann. de Chim. et de Phys.* and *Arch. de l'Electricité*, passim; *Treatise on Electricity and Magnetism*, vol. ii. (1855).

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CHAP. III.

PHYSIOLOGICAL OR THERAPEUTIC APPLICATIONS.

General View of the Application of Electricity to the Art of Healing, and Description of the Apparatus employed.

THE effect that is produced upon all organised bodies, and particularly on the human body, by an electric discharge, was, among the phenomena which we owe to electricity, one of those which most quickly attracted the attention of learned men immediately after the discovery of the electric machine and the Leyden jar. Thus, since the year 1748, Jallabert, at Geneva, entertained the idea of submitting some invalids to electrical treatment, by drawing sparks from different parts of their body, which he brought near to the conductor of an electric machine. He thought he discovered that electrization animated the circulation of the blood; that it was capable of awakening dormant sensation, and to recall into movement a paralyzed organ; and that it produced involuntary convulsive movements. He succeeded, if not in curing, at least in considerably ameliorating the condition of a man who had the right arm paralyzed, especially as to feeling, whose hand and fore-arm were withered, on electrifying it, whether by sparks or by powerful shocks.

Later, the Abbé Sans, and Sigaud de la Fond, obtained a very great number of cases of cures of paralysis, more or less complete. In 1781, Mauduyt published several observations, from which he concluded that the application of electricity was favourable in paralysis, and in all cases where it was necessary to fluidify the liquids and to give tone to the solids. He generally applied electricity under the form of an electric bath; that is to say, in placing the patient on an insulating stool, and in putting him into communication

with the conductor of an electrical machine. The effect, if there really were one, could only proceed from the escape of the electricity into the air. They have also since, in this mode of treatment, drawn sparks from the different parts of the body of him whom they would electrify, by bringing near to them uninsulated metallic conductors, or simply the hand of the operator, or again, brushes formed of numerous wires, in order to make the electricity come out from more points at one time. It is, above all, to cure paralysis that this mode of electrization was applied. The Abbé Bertholon, Mazars de Cazelles at Toulouse, Cavallo in England, and many other authors, quote a very great many cases of cures produced by electricity, but also many cases of non-success. What always strikes one in these works, and particularly in those of Bertholon, are the false theoretical ideas on which they relied. The fact is that, far from generalizing, the medical application of electricity was every day more forsaken, until the time when they tried to employ it under the form of a current, produced by the voltaic pile. But before passing to this new mode of application, we should add, that they had tried to make use of condensed electricity, such as is found, for example, in a Leyden jar, in causing the discharge to pass through a part of the body. These very strong shocks are not harmless; they are capable of doing much harm, in disarranging all the nervous system, as in some cases they have also been seen to produce remarkable cures. This kind of action is, on the small scale, similar to that of lightning, the fall of which is more often fatal to him who is exposed to it, but which has sometimes though rarely, been seen to produce the cure of inveterate paralysis. We shall again refer to the actual effects of lightning, when we are treating of the influence of atmospheric electricity on living organisation. Let us only remark, that M. Thillaye gave, in 1803, a great number of useful precepts on the medical application of ordinary electricity,—precepts which are followed to this day, and which are extremely simple; such as to use metallic brushes, held by an insulated handle, and put into communication with the

conductor of the machine; first of all, to give electricity in its most mild form, and augment it gradually to as much as the invalid is able to support; not to prevent, when electrization is applied, the employment of other means acting in the same direction,—such as frictions, blisters, purgatives, &c.

The idea of applying galvanism, or the electricity of the battery, to therapeutics, ought to go back to the remarkable experiments of M. de Humboldt on the galvanic irritation of the muscular and nervous fibres. But Aldini, the pupil of Galvani, is the first that directly occupied himself in the application of galvanism to medicine, to which he devoted the greatest part of his work, published at Bologna in 1804, under the title of *Theoretical and Experimental Essay on Galvanism.* Galvani had, it is true, in his important electro-physiological researches, glanced already at this kind of application; but he did not follow up its realization. We find in the works of Aldini, in the midst of inadmissible theoretical ideas, a very great number of curious facts on the effects of electricity, in the numerous pathologic cases in which the author had applied it. Nevertheless, it does not result from this that it can take a rank among the curative methods generally adopted; however the trials are continued. Sarlandières, in order to introduce the current more surely into the interior of the body, made use of acupuncture in the treatment of gout, of rheumatism, and nervous affections. He likewise first announced the idea that was put into execution by Pétrequin, of employing this means for the treatment of aneurisms. Two or more fine needles of steel or platina, placed across the aneurismal tumour, are put in connection with the two poles of a battery, which produces the coagulation of the blood contained in the arterial expansion which characterises aneurism, and consequently the cure of it. This effect, which is rather an indirect result of the action of the electric current, since it depends on its chemical and not on its physiological properties, is of the same nature as the application of the current in the treatment of vesicle calculi devised by Prevost and Dumas; we

will occupy ourselves with it in a special manner in the Section that we shall devote to the indirect therapeutic action of electricity.

We cannot dwell upon the numerous publications where electricity is recommended as a curative medium. In 1828, Fabré Palaprat published a translation of a work of Labaume, preceded by a preface, in which the translator rivalled the author on the wonderful effects of electricity, which, according to them, is a sovereign remedy for almost all maladies. However, Labaume admits that galvanism must not be employed for acute inflammatory maladies and nervous excitements; on the other side, Fabré Palaprat is said to have succeeded in curing himself of a nervous malady, to which he had been subject for several years, by introducing a needle successively on the two sides of the cranium, in the region of the brain, on the bone itself, and another needle in an adjoining part. The two needles having been put into communication with the poles of a battery, they were electrified by a shock,—that is to say, by interrupting the circuit at periods very close to each other, the current being directed sometimes in one direction, sometimes in another; and, at the end of several months of this treatment, the cure was complete. Magendie has also proved the happy influence of voltaic electricity in several nervous affections, particularly in those of the organ of sight; his very numerous experiments have in several cases given favourable results. He has recognised that voltaic electricity acts particularly in neuralgia, more especially when the current is made to pass in the course of the affected nerve.

It is in the cases of paralysis in general, that the application of voltaic electricity seems to have given the most satisfactory results. An Italian physician, that we have already had occasion to mention more than once, M. Marianini, relates, in a memoir published in 1833, a very considerable number of cases of paralysis treated by means of voltaic electricity. He makes use of ordinary batteries, copper and zinc, in a pile, simply charged with discs of cloth, moistened with salt water, and composed of a number of pairs, more or

less considerable (50 to 100) according to circumstances. To give an idea of the manner in which he operates, we shall relate the case of a young woman, 23 years of age, whose two legs being deprived of movement had no sensation from the extremities of the great toes to the knees, whatever was the object with which she was touched, whether hot or cold, pointed or cutting. M. Marianini first directed 150 shocks to be given to one leg, and afterwards an equal number in the same manner, to the other; then 300 shocks to both of them simultaneously, by making one of the feet communicate with the positive pole of the apparatus, and the other with the negative pole. They allowed an interval of one or two seconds between each shock, and a rest of two or three minutes after they had given 40 or 50. Some slight contractions and movements of the feet seemed to accompany the circulation of the electric current. During the interval from one series of shocks to the following, the current was sometimes made to circulate in an uninterrupted manner across the limbs of the invalid; sometimes, also, they electrified the invalid by putting the extremity of the negative electrode (which terminated in a sharp point) in contact with the region of the leg, where the skin seemed the most delicate, and which they had moistened with salt water. The invalid then felt a slight pain, similar to that which would have been occasioned by a prick. This was the first sensation she had felt since the commencement of her illness. They every day increased the number of shocks, which were carried up to 800; as also the number of pairs of the battery, which at first were 58, and afterwards rose to 75. The treatment lasted an hour every day; it was only twelve days after it was first commenced that an amelioration was perceived. The invalid successively felt different sensations, and at the same time the possibility of making some movement; and at the end of sixteen days, she could walk without fatigue, and was electrified for the last time. In this case, as in other cases of cure cited by M. Marianini, they relinquished electric treatment when they saw that the invalid was likely to recover; and they left the latter to finish the recovery quite alone.

One cannot deny that, if the cure was not entirely, at least it was greatly due to the application of voltaic electricity; although this same application has not had satisfactory results in other cases of the same nature, treated in the same manner by M. Marianini, who, notwithstanding, still continues (in 1857) to make use of this same treatment, and not without success.

M. Nobili, having remarked in his electro-physiological researches that, when tetanus had been given to a frog by the passage of an electric current, he succeeded in relaxing its muscles by the action of a contrary current, had believed he could conclude from this, that it might happen that the action of an electric current, guided in a given direction, might serve to calm if not to cure tetanus in man. M. Matteucci relates, in fact, a case in which he obtained this cure; but, it is true, that the patient died afterwards from the effect of accidents of another nature, occasioned by the wounds that had caused the tetanus. It does not seem, however, that this curative method has had more success than so many other trials in this terrible malady; perhaps this is owing to its not having yet been applied in a proper manner.

In the midst of so many trials and contradictory results, we quote, as representing well the state of the science in respect to the therapeutic application at the time when it appeared, an article by MM. Andral and Ratier, published in 1831, in the *Dictionary of Medicine and Practical Surgery.* We there find a summary of the work of M. Andrieux on medical electricity, in which are announced several propositions, of which the following is the principal; namely, that, in the actual state of our knowledge, electricity produced by different apparatus can be introduced into the domain of therapeutics, not as a specific means applicable in all cases without distinction, but as an extremely powerful physical agent, the effects of which can be foreseen, calculated, modified, and directed, with more prevision than can most of the known medicaments; and with which one can excite in the economy the most diverse phenomena, and

consequently may present a very great number of curative symptoms. M. Andrieux greatly restricts the *class* of diseases in which he believes electricity can be employed; he thus thinks it is only the immediate effects of electricity that can be relied on.

The experiments have multiplied as much in Italy, England, and Germany, as in France. M. Rayer introduced since 1830, during his service at the Hospital of Charity, a trough battery, and made it serve in the treatment of all kinds of paralysis; M. Andral also employed electricity in several maladies. They generally made use of a trough battery, of a smaller or greater number of pairs, weakly charged. They also tried, in Germany and in England, the application of electricity in laborious accouchements occasioned by the insufficiency of uterine contractions; but experience does not justify the hopes they had conceived of it.

The discovery of induction currents brought another important phase in medical electricity. We have seen that they sought, in the employment of the battery (it is thus that M. Marianini operated), to obtain a series of shocks resembling the series of electric sparks, rather than a continuous current, the effect of which was hardly sensible, except at the moment of its commencement and at the instant of its cessation; saving in some cases, as when it acted on the organ of sight. Now, induction currents, which are a series of instantaneous currents, succeeding one another very rapidly, accomplish much better than the currents of the battery and electric sparks the desired conditions, especially as stimulants, since in general the physiological effect of the current only takes place at the moment of its establishment, and at that when it ceases. We have seen the prodigious effect of these currents on animal organization, in the experiments of M. Masson, who made use of the current of a pile, which he transmitted through the induction coils, and which he rendered discontinuous by means of an electric wheel. M. Neeff of Frankfort was one of the first to make use of these currents, in a medical point of view, employing for producing them a very simple apparatus, founded on the

same principle that I have applied to the construction of the instrument that I have named "Electrical Condenser,"* namely, the use of a movable armature, submitted to the action of a soft iron core, placed in the interior of the bobbin, and intended to establish and to interrupt the circuit of a voltaic pair, the current of which traverses one of the wires of the bobbin, to produce magnetization, which causes a succession of induced currents to be in the other wire. We have already described M. Bonijol's box†, the introduction of which into hospitals for producing induced currents, in respect to medical applications, soon spread, and gave happy results in the cases of local paralysis. They likewise made use of the induction apparatus of Clarke and Saxton‡, in which the current produced by the battery is replaced by a fixed permanent magnet, the movable armature of which is surrounded by a wire, in which are produced the induced currents. But these more massive apparatus have the inconvenience of not being able to give currents of sufficiently variable intensity; the same fault cannot be found with Ruhmkorff's apparatus, which they also make use of; as also of many other induction apparatus, constructed with a view to the wants of physics, and the description of which would be a repetition, since it has already been done in a complete manner in the Fourth Section of Chapter the Fifth in our Third Part. We will confine ourselves then to describing such of those instruments which have been contrived exclusively with a view to medical application, in joining thereto the description of various electric apparatus, and among them a particular species of voltaic pile, likewise constructed with the same end in view.

One of the induction apparatus most anciently employed, particularly in the hospitals of Paris, is that of M. Breton Brothers (*fig.* 431.), in which, following the system devised by Mr. Page, the bobbins are placed round the branches of an ordinary horse-shoe magnet, which is fixed, whilst a movable armature of soft iron is put in rapid rotation before the polar faces of the magnet. The variations of

* Vol. I. p. 385. † Ib. p. 383. ‡ Ib. p. 377.

intensity which result in the magnetism of the magnet from

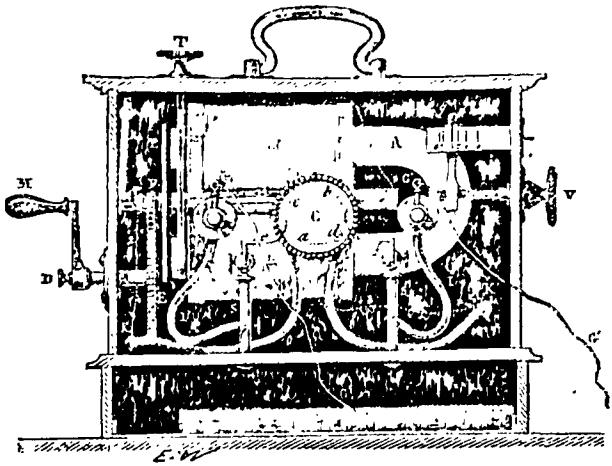

Fig. 431.

the passage of the armature before the poles, is converted into induction currents in the wire of the bobbins. To graduate their apparatus, in order to have currents more or less strong, MM. Breton make use of an adjusting screw, with which they bring farther off or nearer to the magnet the soft iron, which turns at its extremity. The soft iron armature is put into rotation by means of an endless chain, which communicates with a handle exterior to the box which encloses all the apparatus. This instrument, as may be seen, is very simple, requiring no preparation, and always ready to act. Since it contains no battery, it will act for entire hours without its power being weakened. Its strength, which can be very great, depends not only on the distance of the armature from the poles, but also on the velocity with which the intermittences succeed each other; in fact, for each apparatus, it depends on the length and fineness of the wires of the bobbins. The only inconvenience which this apparatus in this respect presents, is that the fixed horse-shoe magnet becomes de-magnetized a little with time, and requires to be re-magnetized; but this weakening in well-constructed apparatus is not manifested until after the lapse of many years. MM. Breton are not satisfied with a single bobbin; they coil two

wires round the branches of their magnet, one larger and the other finer; so that at will a current can be had of stronger or weaker tension. It is the magnet which acts directly on each of these wires, only a little stronger on that to which it is nearest. One or other of these wires is made to communicate by their respective extremities with conductors, from whence the wires designed to serve as electrodes to the currents come out. It is evident that one can thus collect a succession of induced currents, guided alternately in contrary directions, which are developed by the diminution and augmentation of intensity, which result in the magnetized bar, from the approach and recession of the soft iron armature. If one would operate with a succession of currents, all travelling in the same direction, we must employ a commutator, C, formed by a wheel, the teeth of which are alternately of metal and ivory; and which, moved by the same action as the handle, is arranged in such a manner as not to close the circuit, except for one of the two induced currents, that which results from the approximation or recession of the armature.

A modification has been introduced by MM. Gaiffe and Loiseau in the apparatus of MM. Breton. It consists in that the soft iron armature is itself surrounded, at its extremities, by two helices, as in the apparatus of Clarke and Saxton, which produces new induction currents, which can be combined with those that are manifested in the helices which surround the magnet itself.

M. Duchenne has also devised an apparatus of the same nature as the preceding ones, in which induction is produced by a permanent magnet; but, before we describe it, we should speak of that by the same philosopher in which the induced currents are produced by the magnetization and demagnetization of soft iron, and, consequently, by the intervention of a voltaic battery. The two apparatus of M. Duchenne have been constructed essentially with a view to the application that he has made of them to local electrization.*

* M. Duchenne designates by these words the method that he has devised, and by means of which he was able to act exclusively on certain organs,

The first apparatus is that to which M. Duchenne gave the name of *Volta-Faradic*, in order to recall the idea that the induced currents discovered by Faraday are produced by the intervention of Volta's battery; whilst he called the second *Magneto-Faradic*, because it is the intervention of a magnet, not that of the battery, which determines the induction.

The Volta-Faradic apparatus (*fig.* 432.) encloses in a lower drawer a voltaic pair, composed of a small zinc trough,

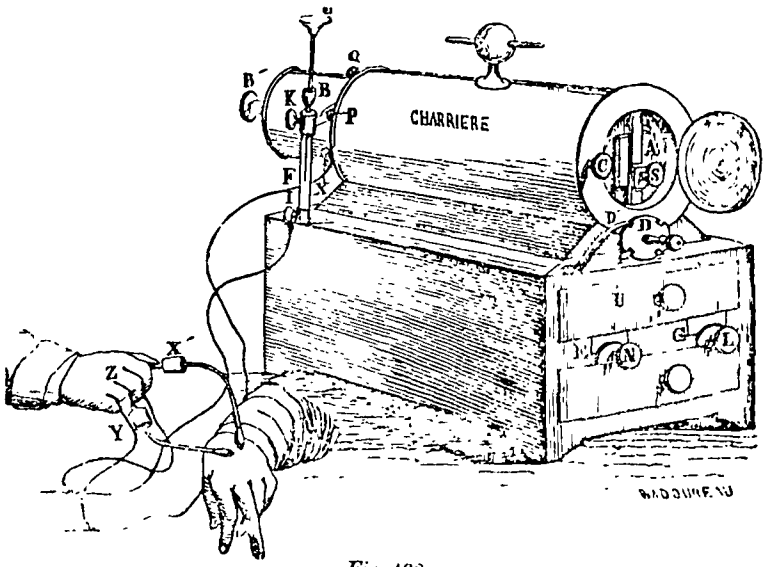

Fig. 432.

wherein is a layer of salt-water, with which is in contact a horizontal plate of charcoal, impregnated with nitric acid, approaching as near as possible to the bottom of the zinc trough. Precautions are taken that no acid vapour can escape from the drawer which encloses the battery, and come and affect the other parts of the apparatus.* Two plates

among others on certain muscles, and thus to make dissection of them on the living subject. This method will be the object of our analysis and examination in the following paragraph. For further details we must refer to his book on *Localised Electrization, and its Application to Physiology, to Pathology, and Therapeutics*, Paris, 1855, in 8vo., with plates.

* This battery has a very remarkable duration of action. M. Duchenne has observed that it is only after five or six months of frequent use that the salts which result from the internal chemical action of the battery diminish its

of copper, in contact the one with the zinc the other with the charcoal, carry the current to two plates of platina, E and G, by means of the screw terminals L and N. It is on these plates that the extremities abut of the great induction wire, which is a copper wire of a $\frac{1}{25}$ inch in diameter, and coiled in a helix round a bundle of soft iron wires. The induction wire, finer, and also of copper, $\frac{1}{50}$ inch in diameter, is coiled round the preceding wire. Its extremities abut on the terminals P and Q, from which pass two wires serving as electrodes. The movable armature or vibrator is composed of a movable soft iron and of a platina screw, S, against which the soft iron is repelled. The rapidity with which the vibrator executes its movements renders it valuable in many instances; but, although we can by means of its spring and of some pieces of movable soft iron with which it is furnished, regulate its action, and render it more or less rapid, yet it is important to be able to have a more sure and more exact means of diminishing or augmenting at will the number of intermittences in a given time; it is the office which the tooth wheel D fulfils, fixed outside the box on the base of the apparatus, and which is turned with the hand by means of a handle; it presents on its circumference four teeth, upon which rests a plate of copper, D', which forms a spring. We can then, according to circumstances, make use of the vibrator or of the toothed wheel. Three other pieces are also joined to the apparatus. There is first a galvanometer, or a rheometer, intended to measure the intensity of the current, and consequently the degree of magnetization of the soft iron of the bobbin; it is a simple compass needle, surrounded by a wire that the current traverses. We can, by means of this galvanometer, regulate the intensity of the current of the couple, so as to be certain of always operating

power by depositing themselves. To restore the battery to its primitive strength, the charcoal must for several hours be plunged into water in which all the salts are dissolved; then, after having allowed it to dry, to charge it with nitric acid, as if it were new. Particular care must be taken as to the choice of the charcoal. M. Duchenne has succeeded in fabricating one which, less hard than that which is had from the gas retorts, and yet sufficiently so to be durable, is found sufficiently porous to be impregnated easily with nitric acid.

under the same conditions. But we must, while still relying on these conditions, have the means of causing the intensity of the induced current to vary. M. Duchenne contrived this in two ways; 1st, in making use of the moderator; 2nd, in making use of what he named the *graduator*. The moderator, which he has already made use of for a long time in apparatus of the same nature *, consists of a glass tube filled with water, terminated at its lower extremity by a metal bottom, to which is soldered a knob, I, and at its upper extremity by a ferrule, from which comes a small hook that serves to place the rod of the moderator in communication with one of the knobs P or X of the induced currents, in order that the moderator may be situated in their circuit. In the upper ferrule is placed a small cork, which is traversed by the rod J of the moderator, which can be lowered or raised, so as to bring its extremity nearer to or farther from the metal bottom which communicates with one of the conductors, whilst the other conductor comes from that knob which is not in communication with the rod. In this manner we are able to cause the thickness of the bed of water that the current has to traverse, to vary within very wide limits; and consequently to modify its intensity to the point of rendering it almost null, which is necessary when very delicate nerves, like those of the face, are in question. Even the variations that are obtained with the moderator, being still very great, however feeble the excursion of the rod may be, M. Duchenne succeeds in subdividing them into excessively small quantities, by means of what he has termed the *graduator*. The graduator depends upon the influence that is exerted over the intensity of the induced currents by a continuous metal envelope that separates the bundle of soft iron from the wires of the induced bobbin. This influence, discovered and carefully analysed by Dove †, which is due to the development of induced currents in the metal envelope itself, consists in a more or less considerable weakening

* M. Bonijol had already added it to his induction box in 1840, with a view to medical applications of induction electricity.

† Vol. I. p. 423.

of the induced currents in the wire of the bobbin. M. Duchenne conceived the happy idea of turning this property to a useful account for the construction of his regulator, which consists of a copper cylinder, P, which envelopes the bobbin, and at the upper part of which exists a graduation scale. It can be caused to advance or to recede, so that it covers the bobbin more or less, and even totally or not at all. A second interior cylinder, similar to the former, envelopes the bundle of soft iron, and is able also to move in the same manner. Its action is naturally more efficacious than that of the former. M. Duchenne has found that their combined action permits of still more subdividing the intensity of the currents. The graduator and moderator work in constant combination; they begin by endeavouring to obtain with the moderator currents of the desired intensity; then, when once this intensity is obtained, it is made to vary in minute proportion with a remarkable delicacy, by causing the graduator to move on some twentieths of an inch, in one direction or the other.

M. Duchenne's Magneto-Faradic apparatus (*fig.* 433.), like

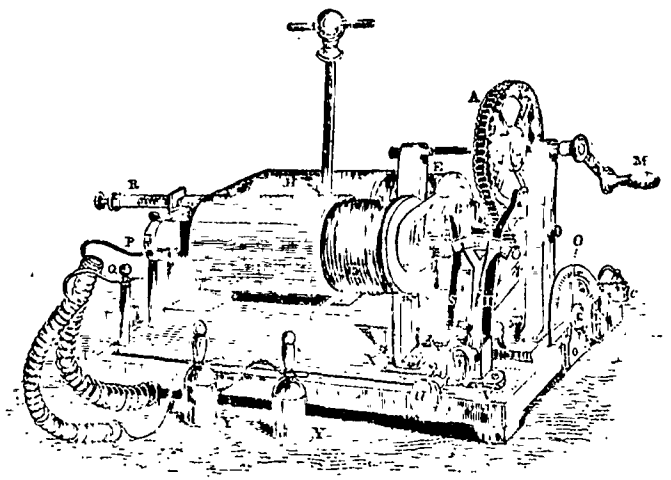

Fig. 433.

the apparatus of the same class, is composed of two magnetized bars, connected at their extremities by a transverse piece of

soft iron. These bars are each covered with two bobbins, one of which, the nearest one to the magnet, is made with a copper wire, $\frac{1}{50}$ of an inch in diameter, and about 80 ft. in length; the other, which covers the former, of a wire $\frac{1}{75}$ of an inch in diameter, and 1968 ft. in length. The two copper wires are wound in the same direction, and are soldered together by two of their ends, which terminate at the same knob. The other extremity of the former abuts at the springs S, which bring about the intermittences upon the commutator B; and the free extremity of the latter, at the knobs to which are attached the conductors intended for conducting the currents. We are thus enabled easily to obtain separately the induced current of the former wire, and that of the latter. In other respects, the apparatus, with some trifling difference, is constructed like other apparatus of the same kind. By causing the great wheel to make two revolutions per second, 64 intermittences are obtained in the same space of time. The movable plate F, upon which are established the armature and its motor-system, may be brought nearer to or farther from the magnet, by means of the adjusting screw N, which enables us to obtain currents of greater or less intensity. Finally, the apparatus is furnished with a commutator and a graduator, composed of two movable cylinders of brass, each of which envelopes one bobbin, and which slide by means of a rod, R, that carries divisions.

Independently of the apparatus that we have been describing, there exist a great number of others, which are merely more or less happy modifications of the former. Thus, M. Hipp, at Berne, manufactures some, which are of so small a bulk that they are entirely enclosed, battery included (for they act by the battery), in a box of less volume than that of a cubic decimètre (61 cubic inches). That of M. Eric Bernard, of which M. Bouvier, in his Report to the Academy of Medicine, gives a detailed description, is also of small volume; it acts by means of a small Grove's battery; its interrupter moves by means of the movable armature, but by the intervention of a platinum plate and point, the contact and the separation of which

determine the passage and the interruption of the current.* As in M. Duchenne's apparatus, there are two bobbins, one formed of a finer and longer wire, the other of a thicker and shorter wire. The apparatus of MM. Legendre and Morin presents a still smaller volume; the box which contains it encloses on one side a small battery, constructed upon the principle of that of Bunsen, and on the other, the bobbin; the latter is composed of several wires, the currents of which may be collected separately. We may also mention an apparatus of M. Déchargé's, a constructor of philosophical instruments at Paris; and one of M. Bianci's, in which the interruption is made by means of needles, which plunge into mercury, as in Ritchie's rotating apparatus.†

It follows from this brief statement, that the apparatus provided for furnishing medical electricity with induction currents, are divided into two classes:—those which may be called magneto-electric, in which the force emanates from a permanent magnet; those which may be named volta-electric, in which it is a voltaic battery (generally a single pair) that furnishes this force. These latter are certainly of more convenient manipulation than the former, since the operator has no wheel to have turned; they present also some advantages in the medical point of view, as we shall see further on. However, we are disposed to think, with M. Bouvier and M. Alfred Becquerel, that magneto-electric apparatus are, all things considered, preferable in medical practice.

While speaking of the instruments intended for the production of induced currents, we have said nothing of an interesting question that has been raised by M. Duchenne, of the special and quite different physiological properties for each of them, which, in his opinion, the induced currents possess that are developed in the larger of the wires,—that which, in volta-electric apparatus, conducts the current of the pair; and the induced currents, that are developed in the second wire, the longer and the finer one. These properties,

* We have described this method, which M. Neeff employed for studying the electric light, Vol. II. p. 267.

† Vol. I. p. 293.

to which we shall return, consist of this:—that the former exercise a more special action upon muscular contractibility; and the latter a more special action upon cutaneous sensibility and upon the retina, as well as a more easy penetration into the organism. For the present, we have nothing further to do than to see what is the physical difference that exists between these two species of currents. It is in the following Section that we shall study their specific properties in a physiological point of view.

We may in the outset remark, that we cannot admit, with M. Duchenne, that the induced currents in the first wire are the origin of the induced currents in the second. In magneto-electric apparatus, it is evident that the magnet acts equally upon both wires, with a little more force merely upon the one that is nearer. The first cannot have any action upon the second, unless its circuit is closed,—a case in which it slightly weakens the induced current in the second wire, as a metallic envelope would do. The two currents are not of a different order; they are two induced currents of the first order, but induced in wires of different lengths and diameters, and placed at different distances. There can, therefore, be no difference between these currents, except a difference of *quantity* and *intensity*, arising from the fact that one of the wires is larger, shorter, and nearer; the other longer, finer, and more distant. The currents of the first wire, when they traverse good conducting bodies, must produce more effect in them; the currents of the second wire will more easily traverse a more imperfect conductor, on account of their greater tension. It is easy already to anticipate, in the physical differences of these currents, the cause of their difference of physiological action.

But it is especially in volta-electric apparatus that M. Duchenne finds the difference in question; in order to show that it is not due to differences of conductibility, he has employed, in the construction of the first bobbin, a wire of the same length and the same diameter as that of the latter; and he still found the differences that we have been pointing out. Here the question is more complex; we recognise,

with M. Duchenne, that the current which circulates in the first bobbin can readily act upon the wire of the second; since we know that, even when there is no soft iron, induction is brought about; but the presence of the soft iron increases it in an enormous proportion, and the two actions, acting to produce the same effect, are added together. The current induced in the second wire is therefore altogether similar to that which the direct action of a magnet would induce in it, and we can, in consequence, see in this current only a current of the first order, and not a current of the second, as M. Duchenne designates it. With regard to the current induced in the same wire that conducts the current of the battery, and which is manifested at the moment when this current ceases to pass, this is what Faraday, and after him all philosophers, have called the *extra current*. We here recognise that, between the extra current and the current induced in the second wire, there may be other physical differences besides those relative to quantity and intensity; and that, consequently, while still combining the bobbins, so that under these two relations the currents may be similar, they may still differ under other relations. At first, the extra current is never composed except of a single induced current, — that which travels in the same direction as the current of the battery *, whilst the induced current properly so called is composed of two instantaneous currents, guided alternately in contrary directions. This difference may well introduce one into the physiological action; but there is still another, which causes that, on taking in the second wire, — only one of the two induced currents, the one which like the extra current results from the interruption of the circuit, — it may happen that we do not find a complete identity between the extra current and the induced current properly so called; it is when the circuit of the first is arranged in such a manner as to include the pair itself by which it is produced, which must diminish its instantaneity, and at the same time increase it in quantity, as takes place in the electro-chemical condenser that I have described †; whilst the second has ne-

* Vol. I. p. 359. † Vol. I. p. 385.; vol. II. p. 693.

cessarily a circuit all metallic. We shall see further on if these differences may explain the differences of action observed by M. Duchenne.

We have said that notwithstanding the introduction into medical practice of induced currents, currents produced by the voltaic batteries were still employed; we have remarked that, in order to produce this current, the most simple batteries had been employed, — zinc and copper, charged with salt-water, and composed of a greater or less number of pairs. With a view to this kind of application, batteries of a particular kind have been contrived, named *galvanic chains*, which possess the advantage of having a tolerably high tension, and being at the same time of very easy manipulation. Such is Goldberger's galvano-electric chain, which is composed of a series of links of zinc and copper, terminated on the one side by a hook, and on the other by a cylinder of glass; in order to apply it, it is previously dipped into vinegar; but it is evident that it cannot produce any effect, or at most the effect of a single pair only. It is not the same with Pulvermacher's chains, which are voltaic batteries of a very ingenious form, and which present a great number of pairs under a very small volume, and are consequently endowed with a powerful electric tension. The following is the method in which these batteries are fabricated. A long rod of wood suitably prepared is mechanically covered with a zinc wire and a brass wire, which are coiled around the rod without touching each other, but very near to each other; these are imbedded a little into the wood by the pressure that is applied to them in order to wind them. When once it is covered, this rod is cut into pieces of greater or less length, containing a certain number of turns, for example, ten of each wire; at one end the zinc wire is free, whilst the brass wire is attached to a small copper hook, inserted into the wooden axis; at the other end it is the brass wire that is free, whilst the zinc wire is soldered by its extremity to another hook inserted in the axis; the small links each represent a pair or element of the battery, supposing that the wood fulfils the office of moist conductor. In order to

build up the battery, they are hooked one to the other in proper order, so that the hook of the zinc of the first pair receives the hook of the brass of the second, and so on. (*fig.* 434.) In this manner a chain of 10, 20, and even

Fig. 434.

Fig. 435.

100 elements is formed. In order to charge it, we have merely to moisten the wood, by dipping the chain (*fig.* 435.) into water slightly acidulated with acetic acid. A smart shock is then received, when we touch its two extremities with the hand; these shocks endure as long as the chain remains moistened. Instead of a long and narrow chain we can have a short and wide one, by arranging the elements parallel to each other (*fig.* 436.), which forms a battery of

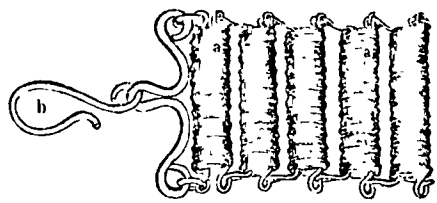

Fig. 436.

much less tension, but more powerful in quantity. The first battery is intended for causing the current to traverse the greatest extent of the affected part, and the second to circumscribe the force of the current within a narrow space.

Instead of having a continuous current, we are able, by

means of these batteries, to procure a discontinuous current, similar to induction currents, when the treatment requires it. Two small pieces of apparatus have been devised by M. Pulvermacher with this object in view. The first, called *interruption-cylinders,* is a small tube (*fig.* 437.) with a copper ring at each end; it contains a spiral metal spring, movable at its free extremity. When it is adapted between two chains, or between one of the poles and the conductor, the current

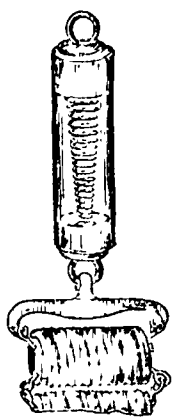

Fig. 437.

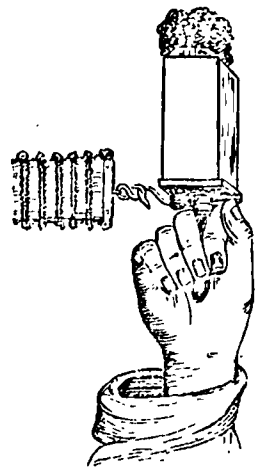

Fig. 438.

is alternately broken and re-established by each movement of the cylinder, which puts this extremity into vibration; thus we have consecutive interruptions, but they are divided irregularly. In order to obtain them regular, we must make use of the second apparatus (*fig.* 438.), the mechanism of which is fixed in a conductor with an insulating handle, by means of which the motion work is wound up. One of the poles of the electric chain is hooked to the movable ring of the instrument, which is set into motion by thrusting a small piece or index of bone, from left to right with the thumb; by thrusting it more or less, the intermittences, and consequently the shocks, are rendered more or less frequent. When we wish to arrest the motion, we have merely to bring back the bone index to the starting point.

According to M. Pulvermacher, there are two modes of

applying the electric chains. One consists in including the organ that we desire to operate upon between the two poles of the chain, so that one of the poles abuts upon the affected region, and that the other is placed upon a sound part, and, as much as possible, upon a nervous centre, corresponding with the affected organ; this is the ordinary method of the application of the electric current, which even permits of our localizing the action. The second manner of employing the chains consists in applying them as belts upon the affected parts attacked either by rheumatism or by neuralgia, taking care to connect the two poles by means of a hook, which is passed into a clasp, straining and consolidating the chain. We do not very well understand the effect of this arrangement, by virtue of which the current is scarcely to circulate in the chain without traversing, at least in a very sensible manner, some part of the body; for not even a derived current can be obtained, on account of the imperfect conductibility of the skin. Morever, no very positive fact has proved the efficacy of this latter mode of application, upon which experience has not yet decided.

The same doubt must be entertained as to the electric girdle and mixtures of the MM. Breton. The girdle is a veritable battery of a single element, composed of two plates of zinc, applied to a double plate of copper, but separated from the latter by a moist mastic. Five knobs, fixed at the extremities of metal wires soldered to the surface of these metals, form so many positive or negative poles, the contact of which with the skin, they say, gives rise to several derived currents, which traverse it in all directions. This electricity is very feeble, especially when the mastic dries; and the skin could be sensible of its action only when it might be deprived of the epidermis in some point. With regard to the electric mixture, it is composed of two pastes, one containing powder of zinc, the other powder of copper, mixed with inert saw-dust and a solution of chloride of calcium, intended for preserving their humidity. Each of these two mixtures is enclosed in a small cloth bag, which is placed in a piece of moist linen; then, through small openings made in these

envelopes, the rod from a metal knob is enclosed and fixed in the middle of each mixture. These knobs being applied to the skin, transmit to it, they say, as do those of the electric girdle, the electricity produced by the chemical reactions that take place in the bags. We do not deny that there may be a production of currents in these apparatus; even the galvanometer indicates their presence; but they are very feeble currents; and we do not see what advantages can be presented by these arrangements, which, at the very basis, rest upon false ideas of the electricity of contact. To sum up, we believe that when we desire to employ electricity in the state of continuous current, the best plan is to make use of Pulvermacher's batteries, which are superior, in point of economy and facility of manipulation, to the ordinary batteries, when the object is to obtain a high tension, which is the case in the kind of application with which we are occupied.

After having described the principal apparatus, the producers of the electricity that is employed in electric therapeutics, it is necessary to add some words upon the methods that are made use of for guiding the electricity into the organs themselves. The mediums, situated at the extremities of the conducting wires, and which are intended to be placed in relation with the skin, the tissues, or the organs, must necessarily be good conductors of electricity: they are of different kinds. They are, first, metallic conductors, generally brass, which are placed in contact with the skin; or cylinders more or less voluminous, intended especially to be held in the hands; or plates of greater or less width, intended to be applied upon a surface of a certain extent; or metallic knobs, balls, cones, of a volume and form that may be arranged at pleasure, according to the use that we wish to make of them, and the part upon which we desire to act. Recourse is sometimes had to straight or curved metallic rods, intended to be introduced to a certain depth into cavities, in order to direct the currents thither. In order better to localise the current, that is to say, to make it reach directly the very portions of the body upon which we desire

it to act, we can even introduce steel or platinum needles into the substance of the muscles, and cause the current to pass between two needles placed at a certain distance from each other, either in the same muscle, or in the same limb, or, finally, between any two points whatever, between which we desire that it may circulate. Notwithstanding some slight inconveniences, which, with skill and address it is not a difficult matter to avoid, this process of electro-puncture possesses many advantages, and, in particular, that of very well localising the action of the currents, and of rousing up much better muscular contraction in muscles that are deprived of it. In default of this method, which besides is not always applicable, sponges are employed, saturated with a conducting liquid, which is in general salt water. Two sponges that are thus moistened, are each lodged in a metallic cup, placed at the extremity of the conducting wires, and in communication with them. These two metallic cups are sustained by insulating rods, intended to be held in the hands of the experimenter; sponges are employed like needles in electro-puncture, in order to cause the current to pass in the desired direction. The employment of sponges is very valuable, in that it perfectly localises the current; and it has rendered very great services in the hands of M. Duchenne. Pincers or metallic brushes are employed when we desire to act energetically upon the skin, in producing cutaneous electrization. The application of electricity by baths, whether local or entire, appears to be susceptible of rendering very great services, by acting as a powerful stimulant in cases of great debility, or anemia reduced to the highest degree, &c.

Analysis of the direct Therapeutic Effects of Electricity.

Before occupying ourselves in a special manner with the direct Therapeutic Effects of Electricity, let us briefly recall to mind its general effects upon the organism. We have, it is true, already studied them in the Fourth Chapter of our Fourth Part; but it is not a useless matter to return to them, especially now that we are able to bring them into

relation with the electric phenomena which accompany physiological actions, and which we have analysed in the First Chapter of the Sixth Part.*

Let us begin by recalling to mind that we have arrived at recognising, as the result of the labours of M. Matteucci and of M. Dubois-Reymond, that the muscles and nerves have an electric state which is proper to them. We have endeavoured to frame in our mind an idea of this state, which consists in a particular arrangement which, under the influence of the vital force, the molecules would assume, that we have regarded, in organic matter as well as in inorganic, as being endowed with two contrary poles. Under the action of the will, or of other causes which determine muscular contraction or sensation, this arrangement is modified in such a manner, that it becomes altogether similar, in the nerve as in the muscle, to what it is in a conductor that is transmitting an electric current. Without returning to the subject, which we have sufficiently developed, we will confine ourselves to dwelling simply upon two points, which possess some importance for the question that is about to occupy us.

M. Dubois-Reymond had attributed the phenomenon of induced contraction, discovered by M. Matteucci†, not to a production of electricity that accompanied the muscular contraction, but to a diminution of the ordinary muscular current, which might take place at the moment of contraction, and which would cause an opposite electro-motive force to prevail; and in particular that arising from the secondary polarities of the electrodes intended for conducting the current. In order to demonstrate that we must not interpret the phenomenon in this manner, M. Matteucci, for closing the circuit, employs, instead of the plates of platinum (plunging into salt water) two plates of distilled zinc, each communicating with one extremity of the galvanometer, and immersed in a neutral and saturated solution of sulphate of zinc. It is easy to satisfy oneself that, by this method, there is no trace of secondary polarity, as M. Jules Regnauld had already seen, who was the first to employ it.

* Vol. III. p. 1.

† Vol. III. p. 33.

Setting out from this, everything being suitably arranged, and the needle of the galvanometer being well in equilibrium, we have merely, as M. Dubois-Reymond does, to place a gastrocnemian or an entire thigh, furnished with its nerves, between the two appendices of moistened paper, which plunge respectively into the glasses filled with sulphate of zinc, in which the zinc electrodes are. After having waited until the needle has stopped, the muscle is made to contract; the needle then deviates rapidly in an opposite direction, which cannot in this case be attributed to the action of a pre-existent electro-motive force. M. Matteucci hence concludes that there is an instantaneous current, or rather a discharge in the muscle at the moment of the contraction, which, besides, appears to us extremely probable; for it is a consequence of the new arrangement which the bipolar molecules, that constitute the muscle, must assume in respect to each other during contraction.

The second point, upon which we think it useful to fix again our attention for a moment, is relative to the very curious experiments of M. de Helmholtz, which lead to the same conclusion. They are relative to the duration of the phenomena of muscular contraction and of the transmission of nervous excitation. By means of very delicate processes and apparatus, and by operating upon the gastrocnemian muscle of a very lively frog, loaded at the commencement only with the weight of a small apparatus, and afterwards with a few small additional weights, placed in a basin, supported by the apparatus, M. Helmholtz has recognised that a certain period elapses between the excitation of the muscle and the moment in which its energy commences to increase. By employing a very ingenious method of continuous currents, combined with induction currents, the learned German philosopher has succeeded in appreciating an interval of time as small as that in question, but sensible notwithstanding. With this view he has employed the method which M. Pouillet was the first to make use of for measuring very short intervals of time, and which consists in observing the effect that a continuous electric current produces upon the

needle of the galvanometer, during the interval that is to be measured.

M. Helmholtz has caused a continuous electric current to pass in a circuit, closed by a piece of metal suspended to the lower extremity of the muscle, taking care that, at the precise moment in which this current began to circulate, an induction current should excite the muscle or its nerve; at the moment when the muscle has possessed sufficient energy to raise the pieces suspended to its extremity, the circuit, traversed by the continuous current, is found to be interrupted; and the deviation of the needle of the galvanometer has enabled us to appreciate the very short time during which this current had circulated; and consequently the duration necessary for the development of muscular energy. By causing the weight that is suspended to the muscle to vary, we have been enabled to measure the durations necessary to the development of the various degrees of energy, and to arrive at interesting results upon the gradual march of the contraction.

In all the first experiments that M. Helmholtz made, the muscle was directly excited by the passage of an electric current; it was by making the current pass through the nerve adhering to the muscle, that he succeeded in rendering sensible the duration necessary to the transmission of nervous excitation. The result of his observations may be formularised in the following manner: — The excitation being produced by a current which traverses a nerve about one fifth of an inch in length, different times elapse between the moment of the excitation and the moment in which the weights suspended to the muscle are raised, according as the excited part of the nerve is near to, or distant from, the muscle.* The most simple explanation of this result is to admit that the transmission of nervous excitation, through a length of nerves of an inch or so, requires a sensible duration;

* The velocity of the propagation of nervous excitation in the sciatic nerve of the frog, is about 100 ft. per second. The cooling of the nerve greatly diminishes this velocity of transmission. It was by cooling the nerves with ice that M. Helmholtz was enabled to prove this result, which is all the more interesting, as it is produced even when the point of the nerve is cooled which is further distant from the muscle than is the point in which the excitation is brought about.

which, as we have already remarked, is a natural consequence of the manner in which, according to M. Dubois-Reymond's experiments, we explain the propagation of nervous action, by attributing it to a material modification in the arrangements of the particles, by virtue of their electric polarity.*

This modification may even be rendered sensible to the eye by means of the microscope, as has been recently shown by M. Amici, who has succeeded, by means of his admirable compound microscope, in forming an exact idea of the structure of the elementary muscular fibre. He has found that a simple muscular filament was composed of a series of discs, excessively thin and excessively near together, connected with each other by means of a great number of infinitely fine threads, going from the circumference of one of the discs to that of the other, like the generating lines of a cylinder. When contraction takes place these threads are seen to enter inwardly, forming a broken line, so as to bring about the approximation of the discs, which, instead of remaining the two bases of a cylinder, seem to be the bases of two truncated cones, opposed by their small bases. There follows, from this change, a shortening of the entire fibre, as it is easy to conceive. With regard to the discs themselves, they are, as it were, a species of rings, the circumference of which, more compact and more resisting, serves as the attaching point to the threads, whilst their central part is filled with a soft matter, analogous to that which is found in infusoria, and which seems to be the matter of which the muscle is formed. This constitution of elementary muscular fibre, which is not a simple hypothesis, since it results from inspection made under the microscope, is altogether calcu-

* We cannot explain the phenomena by supposing that nervous excitation produces upon the muscle an effect less in proportion as the portion of the nerve that is excited is situated at a greater distance from the muscle. Direct experiments have, in fact, shown that muscular energy was exactly the same in the two cases. So long as the vitality of the nerve has not commenced to be weakened, we recognise a complete identity between the electric currents necessary for developing to its maximum the energy of the muscle, by the excitation of two different portions of the nerve, and consequently situated at unequal distances from the muscle.

lated to confirm the opinion that we have put forth upon the cause of contraction. In fact, in the state of rest, and under the influence of the vital force, the particles of each disc or ring have their negative poles turned interiorly and their positive poles exteriorly; but, under the action of any cause whatsoever, the particles make a demi-revolution, which causes their negative poles to turn downward and the positive upward, or reciprocally. It follows then from this that these particles, having their contrary poles placed all near the others in the same rectilinear direction, which is the direction of the length of the fibre, they mutually attract each other, which causes the discs to approach, as actually takes place in contraction.

After having briefly recalled the manner in which the nerves and muscles behave with regard to their proper electric state, let us study more closely than we have done the general and special action that electric currents exert upon them, in order to be enabled to deduce from it, in a more rational manner, their therapeutic effect.

Electricity acts upon organism in two manners: 1st, By stimulating the muscles, and by taking the place of, or increasing the force of, the action which the nerves exercise upon them; 2nd, By stimulating the nerves themselves, and consequently increasing or diminishing the natural action of the nervous centres.

We shall not at present return to the general effect of electricity upon the muscles, which we have carefully studied; but we shall dwell for a few moments upon that which concerns this effect upon the nerves.

We have already seen the effect upon the nerves of the direct and reverse currents. We know that, whatever may be the direction of the current when it is intense, all the muscles to which the nerve is distributed, of which one part is traversed by this current, contract at the moment when the circuit is closed or at the moment when it is opened; and there is at the same time pain. So long as the circuit is closed there is neither contraction nor pain, which is due to the particular state in which the passage of the current

places the nerves and muscles. We likewise know that the contractions are more powerful at the opening than at the cessation of the direct current; and that the contrary is the case when the current is inverse, whilst the pain follows the opposite course. The action of the current upon a mixed nerve of an animal recently killed or living is remarkable. If a continuous current is caused to circulate in it, excitability is diminished or destroyed when the current is direct; it is preserved, and even increased, when the current is inverse. If this same nerve has been traversed by the direct current, repose restores to it very promptly a portion of its excitability; if, on the contrary, it has been traversed by the inverse current, it loses by repose a portion of the excitability which the passage of this same inverse current had imparted to it. The time of repose necessary to a nerve, in order to return in each case to its normal state, is very variable; it is much shorter in very excitable nerves than in others. All these experiments require, in order to their success, feeble and moderate currents; intense currents always diminish the excitability of the nerve, and sometimes completely suppress it for a certain time. This diminution or suppression takes place in a higher degree when the current traverses the nerve from the periphery to the centre than in the opposite direction, which is that, as we have established, of the natural current, that takes place in the nerve at the moment when, under the influence of the brain, this nerve determines the contraction of the muscle to which it abuts.

The hyposthenisant action of continuous currents is a fact that comes out of all the experiments of the class of those which we have been reporting, and which may be turned to a useful account in a manner valuable in therapeutics. M. Remack, by operating upon man with continuous currents, thought that he could prove that these currents possessed the property of causing contraction to cease, by preserving to the muscles the faculty of obeying the will, and in restoring it to them even in the case in which they might have lost it. We can conceive the importance which

this fact might possess for therapeutics if it could be verified in all cases. We have already quoted an analogous fact in connection with the treatment of tetanus by the circulation of a continuous current devised by M. Matteucci.

If the currents that are traversing a nerve, instead of being continuous are discontinuous, the muscles to which this nerve is distributed contract violently, and are, as it were, in a state of tetanic contraction; at the same time, the excitability of this nerve is much enfeebled, especially if it is compared with that of another nerve upon which a continuous current has been made to act. When the discontinuous currents are feeble, and are guided alternately in contrary directions, the hyposthenisant action is very feeble, because the loss of excitability produced by the direct current, is compensated by the increase of excitability determined by the inverse current. When, on the contrary, the currents are intense, the hyposthenisant action due to the direct current becomes a predominant phenomenon. We must carefully avoid in therapeutics the production of this phenomenon, by making use of only feeble currents, guided alternately in contrary directions, when we desire to rouse up vitality, and to exercise a tonic influence over the organic life of the parts upon which it is acting.

We have supposed, in that which precedes, that we are acting immediately upon the nerve with the current; but, in therapeutic applications, this direct action cannot take place except in exceptional cases; it is, therefore, through the skin, by the aid of a moist conductor, that we must exert upon the nerves the action of electricity. As the muscles conduct electricity better than the nerves, it is necessary, in order to be enabled to concentrate the action of the electricity upon these latter, that they shall not be at too great a depth; that they be, so to speak, superficial, or rather in contact only with the tendons of the aponeuroses, or with the cellular tissue; in every case there is never more than a part of the current that traverses the nerve upon which it is acting. M. Duchenne has given the very numerous list of the nerves upon which he has thus suc-

ceeded in directing the currents. We shall return to this further on, when we are occupied in a little more special manner on the action of localised electricity, both upon the muscles as well as upon the nerves. For the present, let us confine ourselves to remarking that there is a great difference between the motor nerves on the one hand, and the mixed or sensorial nerves on the other hand, with regard to the action of currents; these latter being susceptible of suffering some effects of continuous currents, whilst the former do not suffer any, except on the part of discontinuous currents, or of currents which, while still being continuous, present variations of intensity. It follows from this that, in order to rouse the functional activity of mixed nerves and sensorial nerves, we are able indifferently to employ either continuous currents or discontinuous currents, although it may be preferable more frequently to employ these latter, which are more stimulant than the former; whilst for the motor nerves we must employ only discontinuous currents. Thus have we seen paralyses of sensation cured by means of continuous currents, whilst these same currents had completely failed for paralyses of motion.

The study has not been confined to the effects of electricity upon the muscles and upon the nerves; endeavours have likewise been made to determine its action upon the nervous centres. It is to Weber that we are indebted for the most interesting researches upon this point. He has observed that, on the spinal marrow being submitted to the action of discontinuous currents, there are violent tetanic contractions in all the muscles of the trunk; but what is curious is that the marrow does not behave itself as a single conductor of derived currents, which would diffuse themselves to the nerves, but that it acts by the effect of its proper action, which is excited by the passage of the electricity. Among other proofs that the phenomenon does indeed take place in this manner, we may cite the fact that when we make a complete section of the marrow, by leaving the divided surfaces in contact, which does not prevent the derived currents from traversing, but which arrests the

transmission of the medullary action properly so called, on applying the electric excitation to the lower extremity of the marrow, no convulsive movement is obtained in the superior muscles, and there are convulsions only in the inferior limbs; whilst the convulsive movements take place in the one as well as in the others, by applying electricity in the same manner, if the marrow is not cut. The electric excitation of the elongated marrow produces the same tetanic convulsions as those of the spinal marrow. Neither contractions nor signs of heat are observed when we act with discontinuous currents upon the cerebral hemispheres, or upon the brain of a living animal.

With regard to the ganglion nerves, we have been unable to act directly either upon the ganglions, or upon the nervous filaments, but rather upon the organs to which they are distributed. It has been found, that the nerves of organic life determine contractions in the muscles to which they lead only for a few moments after we have commenced to excite them; and that, moreover, these contractions remain after we have ceased to stimulate them. The contractions are even propagated among other muscles besides those among which the stimulated nerves are diffused. Finally, the contractions are executed, and succeed each other, in an order which corresponds to a set object, in respect to the functions of the organ in which they are found. These results, which we borrow from the summary that M. Valerius has made of them, are true only for the muscles which receive their filaments from the great sympathetic.

As we have said above, we shall not, for the present, dwell here upon the effect of currents upon the muscles of the life of relation and upon those of organic life. M. Duchenne, as we shall see, believes that there are differences between the muscles with regard to their susceptibility of contracting under the influence of the same electric currents,—differences which are perhaps due only to the greater or less facility with which electricity is able to penetrate into the various muscles. But that which appears very positive, according to M. Duchenne, is that there exists a great difference be-

tween the muscles, with regard to the sensibility which they present when they are made to be traversed by discontinuous currents; it is evident that this difference is due to the more or less numerous nervous ramifications that are distributed in them. Thus sensibility is very active in the muscles of the face, which are derived from the nerves of the fifth pair. With regard to the muscles of organic life, they contract under the influence of electricity, but in a less degree than those of the life of relation; besides, the contractions are produced more slowly, and endure for a longer time than in the other muscles, after we have ceased to excite them by electricity; such is the case for the small intestines, the stomach, the cœcum, &c. The skin suffers very remarkable effects from the application of electricity, but these effects vary in the highest degree, according to different individuals; the skin of the limbs is frequently seen to present the phenomenon known under the name of *goose flesh*, in which the hairs bristle up, and their bulbs swell outwards; the skin itself contracts, which, according to M. Brown-Séquard, would not be due to the fibre-cells, which are not very numerous in this part of the body, but rather to the cellular tissue, which is itself contractile.

Before examining closely the pathological cases, in which the application of electricity may be a happy resource, it is necessary for us again to dwell, for a few moments, upon M. Duchenne's very remarkable method of localised electrization, which we have only quoted in passing, and of which we have just seen the application in some of the results that we have announced. The facts which have served as the basis of this method consist simply of this,—that, according as the exciters or electrodes of the current are dry or moist, and according as the skin itself is dry or moist, we are able at pleasure either to concentrate the electric action in the skin, or to cause it, without incision or pricking, to traverse the skin itself, in order to confine itself in the organs situated beneath, that is to say, in the nerves, in the muscles, and even in the bones. Also, in order to obtain this result, it is necessary that the electrodes, which are sponges moist-

ened with salt-water, and the skin itself, shall at the same time equally be very moist. Then, neither sparks, nor crepitations, nor sensations of burning are observed, but very variable phenomena of contractility and sensibility are obtained, according as we act upon a muscle or a muscular bundle, upon a nerve or upon a bony surface; cases in which we produce an active pain of a very peculiar character, which makes it necessary that we should carefully avoid placing the electrodes upon such a surface as this. In all other cases, besides those that we have been pointing out, that is to say, if the two electrodes are dry, or if one only is moist, if the skin only is moistened, the electrodes being dry, the electric recomposition always takes place in the skin alone, either at its surface, or in its substance, with or without sparks and crepitations. M. Duchenne has also satisfied himself by many facts, that, when the electricity, owing to the moisture of the electrodes and the skin, goes to seek the subcutaneous organs, it does not act physiologically upon the skin; and, that the sensation produced can only be attributed to the direct excitation of the muscles.

Independently of the precaution that we have just pointed out, localised electrization requires, in order to be complete, the employment of certain currents in preference to others; this results from the comparison which M. Duchenne has made in this respect, between the electricity of ordinary machines and the Leyden jar, that of the voltaic pile, and that of induction apparatus, designating the employment of these three kinds of electricity under the names of muscular localized *electrization*, *galvanization*, and *faradization*. He very quickly succeeded in recognising that, of the three species of electricity, the latter, that is to say induction electricity, is the one that is best suited to muscular electrization, especially when this operation is to be long and frequently practised. Induced currents are able, in fact, to excite the most powerful muscular contractions, without exciting at the same time cutaneous sensibility, without producing shocks, without tearing the capillary vessels, without occasioning, like the ordinary electricity of machines,

all those accidents against which it is sometimes difficult to guard. They are able to act with a great physiological power, without the risk of altering the tissues, as does voltaic electricity by the effects of its chemical properties, — properties which are almost null in induced currents, both because they are instantaneous, as well as because they are in general guided alternately in contrary directions. M. Duchenne concludes from this, as the result of a great number of trials, that induced electricity is essentially medical electricity.

With regard to the mode of operating, it may take place in two manners, either by concentrating the electric action in the plexus or in the nervous trunks, which conduct it to the muscles placed under their dependence, or by directing this action upon each of the muscles, or upon each of their bundles. In these different operations, the electrodes must always be as near together as possible. The first case produces uniform movements; this is indirect muscular electrization: the second gives partial movements; this is direct muscular electrization. Indirect electrization requires the exact knowledge of the distribution and anatomical relations of the nerves; it is very simple upon the limbs, in which the greater portion of the subcutaneous nervous trunks, in one point of their extremity, are accessible to the exciters; it is more difficult and more delicate in other regions. Direct electrization, which consists in causing each muscle or each muscular bundle to contract individually, by placing the moist electrodes upon the points of the skin which correspond to their surface, is very easy, especially in the superficial regions of the trunk and of the limbs, if we possess anatomical knowledge, and especially that of the anatomy of the surfaces. It presents more difficulties for the muscles of the deep regions of the limbs, although the greater part of them present, under the skin, a point of their muscular tissue by which they are accessible to this direct excitation.

We must take care never to administer to the muscles any but a dose of electricity proportional to their degree of excitability, which M. Duchenne believes to be variable for

each of them; — a point which has been disputed with him, and which it is very difficult to establish; since the more or less acute excitation of a muscle not only depends upon its degree of excitability, but upon the greater or less resistance that the electricity encounters in order to arrive at it. Whatever it may be, it is important to be able to graduate the quantity of electricity employed; it is also necessary that the operator should have one hand free, ready to act upon the graduator of the apparatus during electrization, whilst the other hand holds the electrodes by means of insulated handles, and manipulates them easily. They must always be placed at the level of the fleshy mass of the muscles, and not at the level of their tendons; for the excitation of these latter cannot produce muscular contraction. The thicker a muscle is, the more perfect the contact must be: without this, the superficial fibres are alone excited; with very fat subjects, this is especially necessary. M. Duchenne satisfied himself that the more powerful the apparatus are, the more deeply the electricity penetrates. Thus he has seen in cases of saturnine paralysis, in which certain muscles of the posterior region of the fore-arm are wasted and do not contract under the influence of induced currents, the muscles situated below these paralysed muscles enter into contraction, if the currents are sufficiently powerful to traverse them, and to penetrate as far as those that are sound. The exciters, or moist electrodes being in relation only with the external face of the muscles, and the nervous filaments arriving at those of the superficial regions only by their interior face, we are certain that muscular contractions do not take place by the intervention of the nervous filaments. On the face, the partial electrization of the muscles is more difficult on account of the numerous ramifications of the nerves that intersect each other; we may, however, avoid them; for we are warned by the simultaneous contraction of several muscles that the electrode has been directed upon one of the nervous filaments; we then place the electrode a small fraction of an inch higher or lower, and always maintain it upon the direction of the muscle that is to be

electrized. An accurate knowledge of anatomy is necessary in order to avoid these nervous filaments; and this is what has enabled M. Duchenne to limit the electric action in each of the muscles of the face, and to produce the most varied plays of physiognomy.* As the excitability of electric sensibility is very active in the muscles of the face, which is due, as we have seen, to the fifth pair, which sends to them nervous filaments, we must avoid placing the electrodes upon the points corresponding to these filaments; for a very acute pain would result from this, which would reverberate into several points of the face, and even of the brain. M. Duchenne has made a profound study of the electric excitability of the muscles, in respect to contractility and sensibility; it is by means of this study, that he succeeded in possessing the art of causing each of the muscles or of the bundles to contract separately and exactly; but, in order to arrive at this point of perfection it is necessary to possess very great skill, and to be initiated in a host of minute details. Thus, for example, there exists, for each of the muscles an anatomical point, on which the electrodes must be in preference placed, in order to obtain the complete and isolated contraction of these muscles; and it is essential to determine this for each muscle in particular.

We have seen that, on employing the precautions indicated, we may make the electricity reach the muscles through the skin, without the latter being affected; and that the induction currents are the most favourable form of electricity for attaining this object; but there are cases, in which it is important, on the contrary, to direct the electricity to the skin. M. Duchenne considers that for cutaneous electrization, although voltaic currents may be advantageously employed in some cases, induced electricity, which respects the tissues, is here again much preferable. The differences of electro-cutaneous excitability of the various parts of the body, necessitate the employment of the different processes

* He has succeeded thus in causing the different muscles of the face to contract successively and singly, in determining the part played by each of them in the various expressions of physiognomy.

of cutaneous electrization to the number of three. The first mode is cutaneous electrization by the *electric hand:* A moist electrode is employed, a sponge enclosed in a metallic cylinder, which communicates with one of the poles of the apparatus, and which is placed upon a point of the surface of the body that is not very excitable; the electrode that communicates with the second pole is held in one of the hands of the operator, who rapidly passes the dorsal face of his free hand over the points that he desires to excite, after having dried the skin of the invalid by the aid of an absorbing powder (powder of lycopodium or of rice). The second is cutaneous electrization by *solid metal bodies,* cylindrical or conical, which are moved more or less rapidly over the affected parts, after having placed them respectively in communication with the poles of the apparatus. The third mode is cutaneous electrization by *wires.* These wires are employed under the form of a brush or broom enclosed in cylinders, that are held by insulating handles: sometimes the affected surface of the skin is traversed with these wires, which serve as electrodes to the currents; sometimes the skin is struck slightly with their extremities, which M. Duchenne calls *electric fustigation;* sometimes the wires are left at rest as long as the patient is able to support them. This last process, which is rarely supported by the patients, may be designated under the name of *electric moxa.* The three processes differ notably with regard to their degree of energy, and to the sensations which they develope. Thus, the application of the electric hand produces no very sharp sensation except to the face; and this sensation is that of a rough brush that tears the skin. Solid metal electrodes act more powerfully than the electric hand; but they also are powerless upon many parts of the body, particularly upon the hands and upon the soles of the feet. Wires increase in an enormous proportion the power of electrization upon the sensibility of the skin; when they are left at rest, they occasion a sensation similar to that which would be produced by burning needles thrust into the tissues. According to the patients, nothing equals the sensation produced by these

wires, not even fire, such as is applied by the moxa or trans-current cauterization.

The electrization of the internal organs has been an object of long researches on the part of M. Duchenne, who has with this view given more or less varied forms to the conductors intended for conveying the current into these organs; but it is chiefly to the electrization of the organs of the senses that he has devoted very special care, by pointing out the means to be employed, and the precautions to be taken for operating in these cases. We shall return to this a little further on, when we are occupied with it in a therapeutic point of view. We shall only confine ourselves to a remark relative to the different or *differential* effect, as M. Duchenne calls it, of the two induction currents upon the organ of sight.

We have already said that M. Duchenne had found that, in the induction machine, the extra current, that is to say, the one that is produced in the induction wire at the moment of the rupture of the circuit, did not enjoy the same properties as the induced current in the second wire. This latter not only acts more powerfully upon the retina, but also excites more acutely the sensibility of the skin, and penetrates more deeply into the tissues than does the extra current, which, on the contrary, more actively excites the sensibility and contractility of the muscles, and of some subcutaneous organs. The difference between the physiological and the therapeutic properties of the two currents is such, that one or other must not be indifferently employed in practice. We have already mentioned that this difference is essentially due to the fact that the induced current, properly so called, is produced in a much longer and finer wire than the extra current, which causes it to have more tension; that besides it is in general more instantaneous; and, finally, that it is composed of two currents guided alternately in contrary directions, whilst the extra current is composed of but a single induced current, always guided in the same direction. The various experiments of M. Duchenne, are very well explained, without going elsewhere to seek for the

cause of the different effects of the two species of current. Thus he finds that, on employing the long and fine wire helix for conducting the current, the extra current that is in this case produced no longer possesses the properties of induced currents in this same helix when it is under the influence of a large wire helix, which is traversed by the current of the same battery. This is due to the fact that, in the former case, the inducing current is so enfeebled that the extra current is itself of but little power; whilst, in the latter case, the force of the inducing current becoming much more considerable, on account of the better conductibility of its circuit, the induced current to which it gives rise is energetic, at the same time that it has much tension, on account of the length and the small diameter of the wire in which it is developed. This difference between the helices also explains why the course through a same quantity of water much more weakens the extra current than it does the induced current. In questions of this kind, it is necessary to be extremely careful to take account of all the parts of a circuit. Thus, even when two currents have been rendered equal, by means of a certain resistance, interposed in their circuit, and different for each of them, it does not at all follow that they are fit to surmount the same resistance. We believe that it is for want of having appreciated all these circumstances that M. Duchenne thought he had found a specific difference between the two sorts of induced currents,—a difference which is due, as are all those which exist among currents, only to the fact that one of the currents, the extra current, is stronger in quantity, and the other, the induced current, stronger in intensity or tension. We may add that the induced current, properly so called, is composed of currents guided alternately in contrary directions, a circumstance that plays an important part in its physiological action, and which may, in part at least, contribute to the difference of effects observed by M. Duchenne.

It is not only the fact of being directed alternately in contrary directions which gives to induced currents certain peculiar properties; but the greater or less rapidity with

which they succeed each other, exercises, independently of their direction, a very great influence over their physiological effect. The velocity of the intermittences contributes to increase the extent of muscular contraction, because the muscular fibres relax but little, or not at all, in the interval of the contractions, each excitation shortens the muscle more and more; but this velocity in no way influences the energy of the contraction, which depends only upon the intensity of the current. Let a paralyzed muscle, the irritability of which is intact, — for example, the flexor of the fingers,— be made to contract by intermittences alternately rare and rapid; and let a weight be attached to the extremity of the fingers that are set in motion by the contraction of this muscle; we shall observe that the rapid intermittences do not give to this muscle force to raise a heavier weight than do the rare intermittences. But, if the intensity of muscular contraction is not increased by the greater or less rapidity of the intermittences, it is not the same with sensation, which becomes of the most painful character, almost tetanic, when the velocity is considerable. This velocity increases also the tonic power of the muscles; and, when it is prolonged for a considerable time, it is able to go so far as to produce rigidity. Muscular contraction and electro-cutaneous sensibility likewise increase in a notable manner with the rapidity of the intermittences, independently of the intensity proper of the currents that succeed each other. It follows, from what has gone before, that the employment of rapid intermittences is valuable in many cases; first, when the object in view is the study of the individual action of the muscles; because rapid intermittences are able to produce artificial contractions, which imitate perfectly the voluntary motions; whilst, with slow intermittences, we can obtain only muscular contraction without trembling, which prevents, for example, when the face is in question, observing exactly the influence that the individual action of the muscles exercises over the expression of the face. The property that is possessed by currents, which succeed each other rapidly, of acting more powerfully upon muscular sensibility, finds also some happy

therapeutic applications in the very frequent cases in which the muscles have lost their sensibility. It is the same for the cases of insensibility of the skin; even the most intense induced currents are powerless against these anæstheses, if they do not succeed each other with great rapidity. Finally, M. Duchenne has also, in the most happy manner, turned to useful account in therapeutics the property, that is possessed by rapid induction currents, of increasing the power of muscular tonicity, that force which never sleeps, which, in the absence of voluntary contractions, constitutes the physiognomy of the face, maintains the muscles in their natural attitude, and which may be compared to the force of a spring which, if it should happen to diminish or to increase, would derange the best-contrived mechanism. Finally, experiment has shown that the employment of currents with rapid intermittences is necessary to the treatment of muscular atrophies, whether they be complicated with paralysis or not.

There are, on the other hand, cases, in which rapid intermittences might be dangerous; for example, when, after cerebral paralysis, the object is to restore to the paralysed limbs their motive aptitude, we might run the risk, with currents too intense, or which succeed each other too rapidly, of exciting too intensely the general sensibility, and thus exposing the invalid to graver accidents. Even when the condition of the nervous centres might not point to avoiding the employment of rapid intermittences, it is not a matter of indifference to produce electrization with or without pain; for there are persons, such as women and children, who, either from want of energy, or on account of their nervous excitability, are unable to support it; it is necessary therefore to have regard to this circumstance, in order to moderate the rapidity of the intermittences. There are finally, circumstances in which the application of a very small number of isolated intermittences is alone necessary, as when the object is to excite the membrane of the tympanum, in cases of deafness, &c.

We see then that in like manner as it is of importance to furnish induction machines with an apparatus intended to

graduate the intensity of the currents, so also is it indispensable to be able to cause the number of the intermittences to vary at pleasure in a given time. Under this point of view, the employment of a toothed-wheel that is manipulated by the hand, is preferable to the vibrator that acts of itself. M. Duchenne also employs both processes equally in order to render the current discontinuous, employing, according to circumstances, one or the other. With magneto-electric machines, in which a permanent magnet occupies the place of the battery, the rapidity with which the armatures are made to turn before the magnet determines directly that with which the induced currents succeed each other.

After this examination of the method of electrization devised by M. Duchenne, we ought, perhaps, to follow its inventor in the application that he makes of it, in the physiological study of the different muscles of organism; but this analysis would lead us much too far. We must therefore confine ourselves to an important remark. It is, — that electro-muscular exploration alone, while still enabling us to know exactly the action proper of the muscle, rarely teaches which muscles they are whose combination is necessary to it, in order to obtaining the physiological motion which it is destined to execute, and without which it would most commonly produce only accidents and deformities: pathological observation must be added to it, which teaches what are the disturbances that happen to the movements executed by a muscle, in consequence of the defect of the synergic action of one or of several other muscles. It is by producing thus this mutual control of electro-physiological and electro-pathological experimenting, that M. Duchenne has succeeded in determining the individual part played by each muscle, as well as the part of the other muscles in the action of each; and that he thus appears to have found the key of synergic muscular action.

In devoting himself to these muscular explanations, *veritable autopsies made on the living subject*, M. Duchenne has succeeded in discovering the very frequent existence of muscular atrophies, which were confounded with ordinary

paralysis; it is principally pathological facts of this kind, observed in all regions, and under the most varied forms, which have enabled him to analyse with the greatest care the functions of the muscles of the hand, of the shoulders, of the diaphragm, and of the face; and which will enable him to extend his electro-physiological labours in the muscles of other regions. A new and very curious order of facts, to which the application of localised electrization has led M. Duchenne, is relative to the influence of electro-muscular contractility and muscular sensibility over the voluntary motions. Thus he has seen muscles contract by the will, when they have lost the faculty of entering into action by electric excitation; at other times, he has seen muscles which the will could set in motion when it was aided by sight, remain in the most complete inertia when the action of the eyes was defective; a phenomenon due, according to M. Duchenne, to the loss of this muscular property, which he has called, as we have already said, *muscular consciousness.*

We ought not to disguise that some grave objections have been made to certain parts of M. Duchenne's system. The prnicipal are those of M. Remack, who is not disposed to admit the distinction, established by M. Duchenne, between the direct electrization of the muscles and their indirect electrization, by the intervention of the nervous filaments, not thinking that the muscle is susceptible of contracting by the immediate action of electricity, a point which we have already had occasion to discuss in detail.* This physiologist thinks that the particular anatomic *point* for each muscle upon which the electrodes must be placed, in order to produce a complete contraction, is not relative to the direction of the muscular fibres, but rather to the nervous branches placed in the muscle, and which it is the object to introduce into the circuit; these points would be the lateral points of the muscles, or the points of the entry of the motor nerves. From these points, upon applying to them one of the elec trodes, we may command with certainty the muscles, whilst

* Vol. III. part vi. chap. 1.

we place the other electrode upon one other interior nervous ramification. We shall not follow M. Remack into the researches by means of which he supports his opinion, while still admitting the facts observed by M. Duchenne, which he merely interprets in another manner. He arrives at the conclusion, that it is necessary to know the points of the edges of the muscles; that is to say, the points of the entry of the nerves in order to electrize the muscles according to a determined plan and a fixed object. The knowledge may be acquired by anatomy, and even by means of localised electrization. It would be going beyond the limits of a work of the nature of the present to enter into the detail of the discussions raised between M. Duchenne and M. Remack, either upon the object itself that we have been discussing, or upon the questions relative to hallerien* irritability and muscular sensibility, M. Duchenne continuing to assume the existence of this irritability against M. Remack, who disputes it, and persisting in the distinction between these two modes of electrization, the one direct, without the intervention of the nerves, the other indirect, by means of the electric excitation of the nervous branches.

M. Remack, following quite a different direction from M. Duchenne, led by the experiments of Nobili, Matteucci, and M. Eckhard, upon the paralyzing influence which, in the frog, the continuous voltaic current exercises over a motor nerve placed in the circuit, had found that the electrization by a continuous current of the motor nerves in man puts into play the tonic properties of the nerves and of the antagonistic muscles. He was led to believe, as the result of numerous experiments, that the tonic or continuous contractions, which happen in a limb during the passage of a continuous current through a nervous trunk, or in the antagonistic muscles, or in the muscles animated by this nerve, are of a reflex nature, and may consequently be produced also by the galvanic excitation of certain cutaneous

* Under this name is designated the irritability with which the muscular fibre is supposed to be endowed, under the empire of a direct action, and without the intervention of any nervous filament.

nerves. It would follow from this that the continuous excitation of the sensible nervous fibres, which is produced, as is known, by the action of the continuous current, may be transmitted in man as far as the nervous centres, and may even cause continuous contractions of the muscles, that are in relation with the nervous centres, thus excited indirectly. In support of this idea, M. Remack has had the opportunity, in the application of continuous currents to the cure of rigidities, of observing phenomena which compelled him to suppose that the cessation of rigidities is not a purely peripheric fact; but that it is caused by an excitation of the nervous centres. In the case of a great number of treatments, and in particular of those of hemiplexias, he has happened to see that the paralysis of the face or of the tongue, and even intellectual weakness, were diminished, although the voltaic currents had only been transmitted through the nervous extremities. The action of the current was therefore transmitted as far as to the nervous centre; and, as may be supposed, important consequences for therapeutics would be the result of this. Without denying the possibility of this reflex action, we think that it is much less general than M. Remack assumes it to be, and that many of the phenomena, which he has attributed to it, are simply the result of an amelioration in the state of the nerves and the muscles subjected directly to the electric action,—an amelioration, which renders them more susceptible of obeying the action emanating from the nervous centres themselves.

M. Duchenne, who has also made a very detailed study of the electrization of the nervous extremities and of the reflex action, succeeded in recognising that, when the electrization is well localised in the nervous extremities, it never causes the muscles that receive nervous filaments of nerves placed below the excited point to enter into contraction; but that, in order to cause these muscles to enter into contraction, the electrodes must be separated from each other so as to cause the currents to pass from the nervous terminations in the nervous trunks, which is an electrization brought about by a sort of reflex action. This electrization is generally brought

about by placing two of the extremities of the individual—the two hands or the two feet, or one foot and one hand—each into a basin filled with water, into which the electrodes are plunged. Electrization by reflex action acts by exciting the nervous centres, a little after the manner of nux vomica or analogous preparations; however, it rather excites sensibility than muscular contractility. M. Duchenne has consequently applied it to the treatment of certain paralyses in which the nervous centres might be stimulated without danger; however he has not had to congratulate himself generally upon this mode of electrization, which sometimes exposes the invalids to intense pains in the route of the nerves whose ramifications have been excited,—pains which have frequently remained under the form of neuralgias. It may also give rise to serious accidents when there exists an inflammatory ailment toward the nervous centres. M. Duchenne quotes a remarkable example of this: it is that of a young man of twenty-two years of age, who, having been attacked by a hemiplexia, due to a cerebral hemorrhage, thought at the end of a year, when it was very nearly dissipated, to be able to make the continuous rigidity of some of the muscles, which had not entirely disappeared, to cease, by producing electrization by reflex action, in place of limiting the electric action within the muscles. In fact, he had caused induced currents to pass from one of his hands into the other by grasping the electrode in each of them. His life was for several days in danger; and he did not come out of the hospital until after a long stay, having retained in his right side stronger rigidities than those which he had desired to cure.

Examination of particular Cases, to which Electric Therapeutics is applicable.

Now that we have studied in a general manner the application of the physiological properties of electricity in the art of healing, let us enter into some details upon the particular cases in which this application has been usefully realised,

both as a diagnostic and as a therapeutic means, by endeavouring to class these cases according to the principles which must serve as a guide in this matter. These principles flow from two sources: one, experiment made in pathological cases; the other, the physiological phenomena observed in the normal state.

We have already said that we might regard it as demonstrated, that electricity is the means of communication that exists between the nervous centres and the muscles, by the intervention of the nerves; we have succeeded in determining the natural electric state, both of the nerves as well as of the muscles, and the modification which this state undergoes, when there is action from the centres to the periphery, and from the periphery to the centres. This modification consists of a molecular displacement of the particles of the muscles and of the nerves, analogous to that which is produced in conducting bodies, and in particular in electrolytes, such as water, when they transmit an electric current; a displacement by virtue of which the particles are polarised, that is to say, are found to have their similar poles all turned in a same direction. The existence of this property in the nerve and in the muscle supposes that in the sound state these two portions of the animal body have their particles endowed with a great mobility, so that they can easily obey the forces capable of disturbing the natural equilibrium, in which they are found to be under the empire of the vital force, in order to impart to them the arrangement necessary to the accomplishment of their functions. If we examine what the causes are which, in the abnormal state of disease, are able to prevent this accomplishment taking place, we can find only the following: either a sickly state of the muscle, which interferes with the movement of its particles so that they are unable to obey the action of the nerve; or a disease and lesion of the nerve, which prevent the communication of the nervous centre with the muscle, or the muscle with the nervous centre, from operating regularly,—an abnormal state, which may equally exist in the connection of the last nervous ramifica-

tions with the muscles; or, finally, a disease of the nervous centres themselves whence the force emanates which, through the nerves, goes to reach the muscles, or to which the impression arrives that comes from the extremities. We can already conceive beforehand that in this latter case the application of electricity must present little chance of success; since it is not the mode of communication which is wanting between the nervous centres and the periphery, but the possibility of putting into action this mode of communication, a point upon which we can have none but very problematical ideas.* On the other hand we may believe that if the defect is found in the incapacity of the nerve, by becoming polarised, to transmit the impression emanating from the nervous centre or periphery, we may, except for lesions of too heavy character, restore to it its natural aptitude, by developing it artificially, by an electric current of proper

* M. Jacobowitsch has very recently communicated to the Academy of Sciences of Paris, through M. Flourens, the extract of the works that he has executed upon the nervous centres, from which it follows that the whole cerebro-spinal nervous system (the spinal marrow, the elongated marrow, the quadrigeminal bodies, the brain, and the cerebellum) and the entire ganglion system consist, in a general way, of three kinds of nervous elements: the cellules of motion, the cellules of sensibility, the ganglion cellules. We must add to this the cylinders of the axis of all these cells. The ganglion nervous system does not constitute a separate system, it belongs essentially to the cerebro-spinal system. The different cells are the roots of the nerves of the same nature as themselves. All the nerves issuing from the brain, the cerebellum, the spinal marrow, and the elongated marrow, are, according to their origin, of a mixed nature, and they contain filaments originating in different cellules in greater or less proportion, so that there are found in them nervous filaments of motion and of sensation. The nerves of the great sympathetic have their roots in the ganglion cells. An important element, which counts for much in the edifice and construction of the nervous system, is the system of cellular tissue, which not only connects, in the manner of a cement, the isolated nervous elements in the form of groups, which it connects with the different sub-divisions of the nervous system, but which possesses still another feature of importance, essentially functional, seeing that it contains blood vessels, and that it serves consequently in the most important condition of life, that is to say, in nutrition. On killing suddenly by narcotics, such as prussic acid, nicotine, &c., we find that the cellular nervous elements are entirely destroyed, which can only be explained by a sudden interruption of nutrition, which is produced by the action of the poison. This experimental analysis of the nervous system, which the author pursues in the detailed examination that he makes of the different parts of this system, gives us a glance at the possibility, in certain pathological cases, of employing electricity for acting upon the nervous centres, with a chance of obtaining an amelioration. In any case it will have the merit, at least according to the judgment of the celebrated author of so many beautiful physiological discoveries which we have been mentioning, of having shown a great progress in experimental physiology.

intensity and direction. In like manner we may think that on causing the muscle to contract by means of electricity, we may succeed in restoring to its particles that mobility and elasticity necessary for voluntary contractility. We are about to see, by the examination of the results that practitioners have obtained, the extent to which the logical deductions, that we have just deduced from the study that we had made on electro-physiological phenomena, have a foundation.

We may sum up under three principal heads the cases in which the medical employment of electricity is indicated: —1st. To re-establish contractility in the muscles that are deprived of it, when the loss of contractility is not due, or is no longer due, to encephalo-rachidien lesions;—2nd. To re-establish the general sensibility, as well as the special sensibility, of the organs of the senses, when they are abolished or simply diminished;—3rd. To bring back to their normal type contractility and sensibility, when exaggerated or perverted. We sometimes comprehend, under a fourth head, the cases in which it is useful to produce a cutaneous revulsion, which consists of a superficial pain produced upon the skin, as well as a capillary hyperæmia, likewise superficial and transitory. Electricity, in this case, appears to us to act only indirectly.

Paralyses which arise from a lesion of the brain or of the marrow are in no degree susceptible of being treated in the beginning by electricity, as we have already mentioned. All the trials that have been made in this respect have been completely unfortunate; and this would be the case. But it frequently happens that when a paralysis, arising from a cerebral hemorrhage, has not caused the invalid to sink, it becomes better, a resorption is produced, the hemorrhagic focus cicatrizes. This is the result of the natural evolution of the disease, when it is not complicated by relapses — an evolution which requires a variable time, but always very long. Sometimes movement completely returns into the muscles originally paralyzed, with cicatrization of the hemorrhagic focus: sometimes movement returns only imperfectly, or even

not at all. Then it is that the employment of electricity is pointed out for restoring voluntary contractility to these muscles; the more so, as they have never lost, even at the commencement of the malady, electro-muscular contractility. It is a fact established by Marshall, proved by M. Duchenne, then by a great number of physicians, and in particular by M. A. Becquerel, that electro-muscular contractility becomes intact in muscles paralyzed under the influence of a cerebral hemorrhage. This fact demonstrates the vanity of those who pretend to cure cerebral paralyses by the aid of electricity; for, in fine, what do they desire to do? To re-establish muscular contractility: but it is not destroyed. That which prevents its being put into action is the cerebral lesion, which no one dreams of curing by means of electricity. In recent paralyses, so long as the work of cicatrization of the hemorrhagic focus is not completely terminated, the application of the electric currents to the paralyzed muscles is not only useless for restoring motion to them, but may be very hurtful; it has, in fact, been frequently seen that under the influence of the general excitement that always accompanies the local employment of electricity, new cerebral hemorrhages are produced. Although nothing is more variable than the duration of time necessary for the repairing operation to bring about complete cicatrization of the hemorrhagic focus, we may, however, fix this duration from six to eight months; at the end of which we may employ electric currents for the paralyzed muscles whose electro-muscular contractility has been diminished by a prolonged inaction; for those in which it has remained intact will gain nothing for voluntary contractility if they have lost it in whole or in part, this loss not arising from the incapacity of the muscle to contract. But in the former case, which is that in which paralysis, after having ceased to be symptomatic from central organic lesion, is localised in the muscles, the employment of electricity will be useful in favouring the natural tendency of the muscles to resume a part of their movement. M. Duchenne remarks that even then the results will not be happy, except so long as the hemorrhagic focus is

no longer marked except by a scar; but if, after the resorption of the effusion, there remains a cyst of a tolerable size, or if the brain has suffered a considerable loss of substance, then localised electrization does not produce any result. It would be important to be able to perform a diagnosis, at least approximately, of the state of the hemorrhagic focus after the ordinary term of its resorption, in order to know whether it is proper or not to apply localised electrization to the muscles that have remained paralyzed. M. Duchenne, while still recognising that it is very difficult to determine, in an exact manner, the state and degree of the lesion of the brain, found, however, that the invalids who, six to eight months after the commencement of a cerebral hemorrhage, preserved a more or less complete paralysis, but without the least rigidity, have been advantageously treated by localised electrization; which proves that hemiplexia consecutive to cerebral hemorrhage, which is not complicated with rigidity, is no longer sustained after six months of duration by the central lesion; but that it is localised in the muscles which have lost their motive aptitude. It is the reverse if the hemiplexia presents phenomena of rigidity; in this case, if the rigidity of the muscles is permanent, it announces an inflammatory work in the brain; and we must guard against localised electrization. It is not the same if the rigidities are transitory; they may be made to cease, or at least to diminish, by a prudent and well directed application of electricity. But it is especially in the paralyses of the face and tongue that this prudence is necessary; this double paralysis remains sometimes after the resorption of the bloody effusion; not only does it occasion a distension of the features, but the patients suffer from it great inconvenience in speaking and eating. M. Duchenne has very happily cured it by localised electrization; but unfortunately, in three cases out of ten, this electrization has been accompanied by cerebral accidents of greater or less gravity. In order to avoid this danger, it would be necessary to be able to distinguish the facial hemiplexia of a cerebral cause from that which arises from the paralysis of the seventh pair, which may be subjected without the least inconvenience to

this mode of treatment; the only one, frequently, that is capable of curing it. But it is frequently a difficult matter to distinguish the two hemiplexias from each other, on account of the analogy that exists in their appearance. However, when the paralyzed muscles preserve their electric contractility intact, it is evident that the hemiplexia is due to a cerebral cause; on the other hand, when the orbicular of the eyelid is paralyzed, we may be certain that the facial hemiplexia cannot be referred to a lesion of the brain, and that it depends simply on a pathological state of the facial nerve. There exist also other more indirect indications, such as the weight of the head, dizziness, &c., which must not be neglected.

Whatever it may be, even when the application of electricity is indicated in a manner that seems positive, it must be practised with many precautions in the treatment of paralysis consecutive to cerebral hemorrhage. First, it is necessary, at all cost, to avoid electrization by a reflex action; thus, not only is it necessary to take care to cause the currents to pass from the extremities to the nervous centres, by allowing them to traverse the nerves in the direction of their length; but it is even necessary to bring the electrodes as near together as possible in localised electrization, in order that the course of the electric currents may be confined within the organs themselves. It is besides necessary that the intermittences of the currents should be far from each other; because, for a certain degree of rapidity of these intermittences, the sensations become painful, and as it were tetanic; and a general excitement might be the result of it, which, by reacting upon the nervous centres, causes a risk of exciting a congestion, a new hemorrhage,—in a word, cerebral accidents. Besides, as the object here is simply to excite the return of the voluntary movements, by producing artificial muscular contractions, the employment of currents with rare intermittences is perfectly sufficient. We must also take care to excite individually the paralyzed muscles, in order to rouse up the movements in an equal manner, and to re-establish the equilibrium of the muscular forces. Finally,

the sittings must not be prolonged too much, nor must the duration of the treatment be too long, seeing that the muscles not being in a state of atrophy, and not having suffered in their texture, we have nothing else to do than to re-establish voluntary contraction. If, after fifteen or twenty sittings, the muscles do not appear to recover their movements, it is because the cause of the paralysis is seated far elsewhere than in the muscles; that is to say, in the brain. We must wait; and a fresh attempt may be more fortunate than the first.

We shall not dwell upon the paralyses which arise from a softening, or from tumours, developed in the brain. It is evident that the rules to be followed in the application of electricity must be the same as for paralyses due to a cerebral hemorrhage; only if, in the former case, localised electrization is able notably to contribute to the amelioration of the symptoms, or to the restoration of the whole or of part of the movements, when the softening is arrested or in progress towards cicatrization, it is more prudent to proscribe in an absolute manner the employment of electricity in the symptomatic paralysis of a cerebral tumour, on account of the danger that is run by this, of favouring the appearance or the return of sanguine congestions around these accidental products developed in the brain.

The symptomatic paralyses of diseases of the marrow differ in an essential point, according to Marshall Hall, from those which are symptomatic of cerebral affections, namely, in that whilst in these latter the electro-muscular contraction remains intact, it disappears completely in the former. M. Duchenne, while still combating the mode of experimenting of the English physiologists, which is in some points defective, clearly finds, however, as he does, that in lesions of the spinal marrow, muscular irritability diminishes, at least *almost always*, which may be proved by successively conveying the electric excitation to each of the paralysed muscles. Unfortunately for the generality of the law, M. Duchenne has found an exceptional case, in which the electro-muscular contraction had remained normal in all the muscles, notwith-

standing such a lesion, that the grey substance had completely disappeared in each of the two halves of the marrow and on the median line, as was proved by the autopsy of the patient, who had succumbed, several months after, to a continuous fever. However, in all other cases in which he had been able to prove by autopsy an alteration of the other parts of the marrow, M. Duchenne had found a corresponding alteration in electro-muscular contractility. M. A. Becquerel does not go so far even as does M. Duchenne, for he considers that if the proposition of Dr. Marshall Hall is true in general, there would be numerous distinctions to be made for particular cases. He found, on studying electro-muscular contractility in several cases of disease of the marrow, that the degree or intensity of this contractility is in the direct ratio of the conservation of voluntary movement, so that it disappears in an absolute manner only if the paralysis is complete, and voluntary movement entirely abolished.

With regard to the rules to be followed in the application of electricity to diseases of the marrow, it must not be thought of so long as the chronic softening of the marrow is not stationary or in progress towards cicatrization, which is recognised in that the symptoms of paralysis are stationary or decreasing. Even in these cases this application is useless and may even be hurtful if the paraplexia remains complete, and if the electro-muscular contractility is itself almost annihilated; when the paraplexia is incomplete and contractility only diminished, we may have recourse to localised electrization, and excite successively the muscles of the two inferior limbs. M. A. Becquerel advises also as a more simple treatment and requiring shorter sittings, electric baths of the feet, under the influence of which almost the whole of the inferior muscles contract at the same time. These baths are given by means of two little buckets, filled with tepid salt water, into each of which one of the feet of the invalid is plunged, and which communicate respectively with the poles of the induction apparatus. The sittings must be from ten to fifteen minutes, and their number must be always considerable; for it is necessary in sympto-

matic paralysis of the diseases of the marrow, to continue for a very long time the employment of electricity, in order to obtain very slight results.

After paralyses which arise from a lesion of the brain or marrow, come those to which the material lesion of a nerve of motion or a mixed nerve gives rise. A similar lesion, if it is of a certain intensity, may have for its effect, to annihilate motion, and sometimes even sensation, on the muscles in which the affected nerve is distributed. Many causes may determine lesions capable of producing such an effect; some indirect, arising from diseases in the nerves; others more direct, designated under the name of traumatic lesions, arising from accidents that wound or cut the nerves. M. Duchenne has made a very particular study of the paralyses due to this latter cause in mixed nerves, which he has designated under the name of traumatic paralyses of the mixed nerves.

Every traumatic lesion of a mixed nerve occasions a greater or less disturbance in the state of sensibility, of voluntary movements, and of nutrition of the muscles which are dependent on this nerve. It is clear that if all the fibres of the nerve have been attacked and disorganised by lesion, the electro-muscular contractility of the corresponding parts is annihilated, and there is no hope of cure by electricity; it is as if the conductor that is to convey the current to an electric telegraph were totally broken; we might in vain repair the telegraphic apparatus; it would not act any the better for this; but if the conductor is only partially broken, if the accident that it has suffered is more or less repaired there would still be a manifestation of signals on the telegraphic apparatus, provided that care has been taken to put an end to the state of deterioration into which it might have fallen by defect of use or by accident. When, therefore, all the fibres of a nerve have not been destroyed, it may happen that muscular contractility is partially or integrally preserved, even when the voluntary movements are annihilated; we may then hope for a cure by means of electricity. In a case quoted by M. Duchenne, a case in which,

in consequence of the dislocation of a shoulder, a man suffered a paralysis of the corresponding limb, with withering of the muscles of the arm, of the fore-arm, of the hand; all the nervous filaments suffered equally, for the entire limb was emaciated; all its movements equally were destroyed; whence it was natural to conclude that all its muscles were equally affected. Among the muscles some had lost their electric contractility; these were they that had withered most rapidly, whilst the other muscles, likewise paralysed, but without loss of electric contractility, escaped withering, and recovered their voluntary movements, after some sittings of localised electrization. However, although the loss of electric contractility, in certain muscles, might cause a fear that these muscles were lost for ever, M. Duchenne had concluded, from the sensibility which the patient still evinced when the same muscles were subjected to the action of induced currents, that the nervous communication was not completely interrupted; he no longer despaired of restoring to them their vitality under the influence of electric excitation. Only it happened that, before regaining their movements and nutrition, they suffered, under the influence of the treatment, a momentary sur-excitation of sensibility (*hyperæsthesia*)—a phenomenon which, when presented in this case, may therefore be considered as a favourable sign. The following then is the succession of therapeutic phenomena, such as they are manifested under the influence of localised electrization, in the cases in question*: 1st—Rapid return of voluntary movements into the muscles which have not lost their electric contractility; 2nd.—Exaltation of sensibility (*hyperæsthesia*) in the muscles whose electric contractility has been profoundly affected, and whose sensibility was merely diminished; 3rd.—Return of nutrition and then of voluntary movements in the muscles of the arm, then of the fore-arm, and finally of the hand. It is evident that, under the influence of localised electrization, the nerves are

* M. Duchenne has obtained the same results in many analogous cases.

gradually restored to their natural state, so as to be able to establish communication, momentarily interrupted by the effect of their lesion, between the nervous centres and the muscles. The slowness of the cure might perhaps lead one to believe that it is only the effect of time; but the happy influence of localised electrization in similar cases, in which it had been introduced very late, and at a period in which the paralysis and withering were for a long time stationary, shows the utility of this therapeutic agent, at the same time that it proves that time is more frequently insufficient, unless the nerves have been very little affected, and the muscles have lost their electric contractility. A very extraordinary fact, pointed out by M. Duchenne, is that it has sometimes happened that, under the action of localised electrization, the muscles have recovered their voluntary movements, their force, and their nutrition, before recovering their aptitude for contracting under the influence of electric excitation. M. A. Becquerel is not disposed to admit this latter fact, which he regards rather as an exception, upon the nature of which he has even doubts. What is more positive is, that the slowness of the therapeutic action of localised electrization upon the muscles that have lost their electric contractility and sensibility, is due to the fact that, when the lesion of the nerve is not cured, the influence of the nervous centre cannot again be communicated freely to the muscles; and that then the effect of electricity upon them, which consists essentially in restoring to them their aptitude to obey this influence, cannot evidently cause it to be felt again. In this respect localised electrization is able to serve as a diagnostic between muscles which seem to be equally paralysed; M. Duchenne has observed that those among these muscles which have not lost their electric contractility may, it is true, recover their movements spontaneously, but more rapidly, however, by electric excitation than by the simple effect of time; whilst those which have lost it commence by withering, and are unable to gain their nutrition or their movement until, the lesion of the nerves being cured, they are capable of receiving nervous influence;

then only is it that electric treatment may be applied to them with success.

This loss of electric contractility enables us to distinguish paralyses which are due to a traumatic lesion of the nerves, from those which depend on a cerebral cause in which this contractility remains intact. M. Duchenne quotes a striking example of the justice of the diagnostic in a patient where, notwithstanding all contrary appearances, he did not hesitate to attribute to an alteration of the nerves which lead to the muscles, the paralyses which they underwent; now, a minute examination terminated by proving a lesion at the level of the emergence of the nerves which constitute the cervical and brachial plexus of the right side; this local lesion was due to an exostose, which he succeeded in curing, and with it the paralysis that accompanied it. M. Duchenne quotes other facts also in support of the accuracy of his proposition, the importance of which he makes to come out for cases in which the cause of the paralysis is not evident, and in which however a tumour or a deeply concealed exostose may compress a nervous trunk, and produce slowly or suddenly phenomena of traumatic paralysis of the mixed nerves,—phenomena, the nature of which is not doubtful in the ordinary cases in which they are the consequence of the section, contusion, shock, compression, or distension of the nerves.

Electric-muscular exploration is therefore the best diagnostic for paralyses consecutive to the traumatic lesion of the nerves; the gravity of these paralyses is in direct ratio of the weakening of the contractility and electric sensibility of the muscles to which these nerves abut; but, if sensibility is preserved or simply diminished, even when electric contractility is extinct, this gravity is diminished. The electric contractility remains entire in the muscles that have not suffered, but which are sometimes paralysed by a sort of nervous binding; this integrity of electric contractility is a favourable sign, and these muscles rapidly recover their movements.

When the traumatic lesion of a nerve is very grievous,

either by a complete division, or by a loss of substance, we might have thought that the paralyses that were its consequences were incurable. However, M. Duchenne, who had for a long time shared this opinion, and had refused, in these cases, to apply electrization, has subsequently recognised that, although very grievous, the cases of this kind are not to be despaired of. Thus he has succeeded in curing an atrophic paralysis of a shrivelled hand, deprived of movement,—a paralysis that was the consequence of the tearing of the cubital nerve, and which was of four years' standing. He attributed these happy results to the fact that a nerve might be cicatrized when it has been divided, or may be regenerated when it had lost a part of its substance.* He even thinks, from a curious experiment of M. Claude Bernard's †, that, in default of these natural conductors, the central nervous influence may, in the long run, open out for itself a new route, in order to arrive at the organs deprived of their proper nerves, probably by means of the binding property that seems to exist between the nerves of organs that are near together. Would it not also be possible that electrization might contribute, not only to restore to the muscles their aptitude to obey the nervous influence, but that it might be likewise capable of developing in the nerves their essential properties, when they have lost them, as the result of the alterations that they have undergone; and of revivifying the most delicate nervous ramifications, which still remain more or less in the muscles, even when they seem to be deprived of all nervous substance?

Without dilating further on this interesting subject, with which we have now been occupied, let us confine ourselves to recapitulating in two points the principle that must serve

* MM. Follin and Brown Sequard have established, by microscopic researches, that in these cases the nervous fibres are continued without interruption through the cicatrix. Dr. Prevost had already made the same observation in 1827, as the result of very interesting experiments upon the regeneration of the nervous tissue.

† M. Ch. Bernard, having destroyed in the vertebral canal of a dog all the sensitive roots to a certain extent, so that their regeneration was impossible; loss of sensibility was the consequence of this operation. But this sensibility returned progressively, and a year after the operation the animal appeared to enjoy its normal sensibility.

as a guide in the treatment of paralyses consecutive to traumatic lesion of the nerves: 1st, that this paralysis, when muscular contractility is not abolished, must be submitted as soon as possible to the treatment of localised electrization: 2nd, that when, on the contrary, this contractility is lost, or at least insensible, we must wait until the nervous lesion is cured, namely from four to ten months, before the application of electrization. Each muscle must be electrized in a special manner; the more it has suffered in its constitution and in its contractility, the more considerable must be the intensity of the current and the rapidity of the intermittences. M. Duchenne has observed that the best means of acting upon the contraction of withered muscles is, to excite muscular sensibility by means of rapid intermittences; only we must diminish their frequency and moderate the current when we see the sensibility exalted, for fear of provoking neuralgias difficult to repress, and sometimes even inflammatory accidents. Neither must the sittings be too long; and it would be better to operate for a very short time only consecutively on the same muscle, one minute for example, free to return several times during a same sitting upon each of the muscles, leaving a time of repose between each excitation.

Among paralyses consecutive to lesion of the nerves, we will cite that also which constitutes facial hemiplexia: we have seen that this hemiplexia may be a consequence of an affection of the brain. It is not this latter which is here in question. The matter under consideration is isolated facial hemiplexia, which is always due to some morbid affection of the facial nerve, such as a very circumscribed small hemorrhage or softening at the origin itself of this nerve, or in its thickness; such, also, as a compression of this nerve, determined either by a sanguine congestion produced under the influence of a cooling, of a current of air, or by a tumour seated anywhere near the origin of the nerve, or outside the cranium; the wounding of the nerve, its suture, its destruction by abundant suppurations, by gangrene, likewise produce isolated facial hemiplexia. When the facial hemiplexia is not the result of the compression of the facial nerve by a tumour,

of its wound or its destruction, it is necessary, even when electro-muscular contractility is diminished or annihilated, to try to treat it by localised electricity, with all the precautions that we have indicated above; it is only by persevering for two or three months, at least, in this mode of treatment, that we can be able to satisfy ourselves if the paralysis is curable; in some cases, we shall obtain either a complete cure or the persistence of a certain degree of paralysis. A third mode of termination, which M. Duchenne has studied with much care, is rigidity,— an affection, the gravity of which consists in that the muscles that are attacked by it are liable to retract in course of time, and to bring about an incurable deformity, which greatly hinders the movements. When rigidity succeeds paralysis of the face, after we have commenced employing electrization against it, it is generally necessary to interrupt it. We are scarcely assured of avoiding rigidity when we see the muscles whose electric contractility has been more or less abolished by the paralysis of the seventh pair, recover their tonicity in a certain order, and in a gradual manner. Besides, this is a point upon which we shall return in connection with rheumatismal paralyses.

Besides the paralyses that arise from organic lesions in the nervous centres or in the nerves, there are others, whose less apparent cause it is frequently a difficult matter to discern; but in the cure of which electric treatment is no less applicable, and often with success. We will first quote *hysterical* paralyses, which are presented sometimes under the form of paraplexia, sometimes under that of hemiplexia, sometimes under that of the isolated paralysis of a limb, or of a part of a limb. According to M. Leroy d'Etoiles, these paralyses would be due to the more or less prolonged absence of the *nervous influx* (the influence which emanates from the nervous centres is thus indicated), after an exaggerated and rapid expense of this agent. But this explanation, which is in opposition with several cases of cure produced by electricity immediately after attacks of hysteria, could not be admitted. M. Valerius would be rather disposed to believe that these paralyses are due to a deviation of the nervous

influx, which would be diverted by the malady from one organ, in order to be carried to another; nor would it be far wrong to attribute them to a disturbance that has occurred in the electric state of the paralyzed muscles,—a disturbance which would consist in the weakening of the natural electric polarity of these muscles, which electricity might cause to disappear. What is certain is, that hysterical paralyses do not correspond to any appreciable lesion of the brain or of the spinal marrow, and that they are connected with a certain peculiar nervous state. Nothing is more irregular than their commencement, their progress, and their termination. They show themselves sometimes slowly and progressively; sometimes suddenly; but almost always as the result of a not very acute nervous impression; they are equally variable, both in their development, sometimes feeble, at other times intense, disappearing at one point in order to show themselves in another, as well as in their termination, sometimes sudden, sometimes slow. Electro-muscular contractility always remains perfectly intact in every case; and localised electrization is a means of cure that presents great chances of success, except in the cases in which hysterical paralysis is presented under the form of paraplexia. It is necessary in this paralysis to take care to convey the electric excitation into each of the affected organs, and to continue the treatment for some time after the return of the movements, or of sensibility, in order, so to speak, to fix the cure; for the organs resist so much better the lapses to which they are exposed, in consequence of the hysterical fits, as they have been more frequently electrized. M. Duchenne, from whom we borrow these details, adds, however, that there are cases in which a single electro-cutaneous excitation has been sufficient to cure hysterical paralyses. It is, without doubt, by exciting the nervous centres by a sort of reflex action, that cutaneous electrization recovers the movements in hysterical paralyses. This mode of electrization is especially valuable when cutaneous sensibility is considerably diminished in the case that is to come under treatment; however, it is much more painful than treatment by muscular electrization, so that it must be

employed only with patients who are able to support it. In general, the sensation produced by electric excitation is so strange, even when it is not painful, that in order to avoid provoking hysterical relapses with those who undergo it, the patients must be gradually accustomed to the sensation, by commencing by very feeble doses, and with intermittences far apart. We arrive gradually to a localised electrization with rapid intermittences, which is the best mode that is suitable to the treatment of hysterical paralysis; but it is necessary to renounce it when it excites nervous crises, and to supply in its place muscular electrization with rare intermittences. Let us add, however, that some physicians, especially M. A. Becquerel, think that in nervous paralyses recourse must not be had to electricity, except when the other therapeutic agents have failed; and reserve it for the cases in which the paralysis is complete, and already of long standing: he does not doubt but that with perseverance we may obtain a happy result.

Besides hysterical paralyses, there are also other nervous paralyses, upon which we shall not dwell. They are those which are the consequence of some affection, whether local or general, which the patient has suffered, such as chlorosis, certain violent fevers, &c. These paralyses, which are in general designated under the name of essentials, have been often treated with success by electricity; however, we must not exaggerate the extent, in these cases, of this mode of treatment; for essential paraplexias have been sometimes seen to be cured spontaneously, or under the action of the most varied therapeutic methods. However, there are well established cases in which these paraplexias, which had resisted all therapeutic agents, have yielded to the application of electric currents.

Paralyses by *intoxication* belong, also, to the category of those which do not result from any lesion of the nervous centres and the nerves. Among these paralyses, the most frequent and the most important is the saturnine, which affects patients who are subject, by the effect of the trade which they follow, to lead cholics. Saturnine paralysis,

although being able to affect muscles that are most different, attacks, however, the extensors in preference; and directs itself generally to the hands and arms. It is often incomplete, and is manifested merely by a greater or less weakness of the muscles; when it is complete, it is a veritable and absolute paralysis. M. Duchenne regards as one of the most striking characteristics of this paralysis, the abolition of electro-muscular contractility in the muscles that are affected by it. M. A. Becquerel thinks that this abolition is complete only when the paralysis is also so; and that the degree of conservation of electro-muscular contractility is in direct ratio with the degree of conservation of voluntary movement. M. Becquerel's remark is not in contradiction to M. Duchenne's allegation, who himself remarks that the abolition of muscular contractility is not general; and that it always seems to direct itself by preference upon certain muscles, when the entire limb is struck by paralysis. The withering principally attacks the muscles which have suffered in their electric contractility, although the limb struck with paralysis is generally emaciated. These muscles are the only ones which have in reality suffered the deleterious influence of saturnine intoxication. The other muscles of the paralyzed limb suffer little in their nutrition, and very rapidly recover their strength and their voluntary movements under the influence of the treatment.* Whatever it may be, the application of localised electrization presents great chance of cure, especially in incomplete paralysis; and it sometimes even succeeds in complete ones, even when the most energetic

* M. Duchenne has had the opportunity of confirming the accuracy of his assertion by the autopsy of a man who, for nearly twenty years, had retained a saturnine paralysis of some of the muscles of the posterior region of the fore-arm. These muscles, during life, did not contract by electric excitation, whilst those of the anterior part of the fore-arm enjoyed all their properties, although their force was very much diminished, and they were also withered. At the autopsy, the former muscles, those in which electric contractility no longer existed during life, were of a pale yellow; when examined by a microscope, they were found to be transformed into fat; the muscles of the anterior region, on the contrary, had remained in the normal state. It is not, however, until after several years that the muscles appear to commence altering in their texture. With regard to the nature of this alteration, it seems to us to be due to the presence of a certain quantity of lead in the blood, which must suffice in course of time to deprive the muscle, which receives this blood, of its normal properties and vitality.

treatments have failed. It is important, in the electric treatment, to commence by proving the exact state of all the paralyzed muscles, by means either of electro-muscular exploration, or by other diagnostic signs, which require that we should know well the individual action of those muscles. What renders the exact knowledge of the degree of lesion of the muscles of importance, is that the electric excitation must be carried in each of them to a dose stronger, and for a longer time, in proportion as they are more deeply injured. The treatment of saturnine paralysis is, in general, very tedious, and requires from thirty to a hundred sittings. The electrization must be so conducted as to excite painful sensations; because the current must be with rapid intermittences, as intense as possible, and directed principally into the muscles whose contractility and electric sensibility are most enfeebled. It is likewise necessary to act upon withered muscles: and the rapid current is that which exercises most influence over muscular nutrition, at the same time that it revives voluntary movement. The sittings must not last longer than ten minutes; and they must, in general, be repeated every other day. We may add with advantage to the treatment of localised electrization, sulphur-baths, strychnine administered internally, nervous gymnastics*, and shampooing.

It appears to us to follow from the diagnostic, and the treatment of saturnine paralyses, that these paralyses arise essentially from the alteration of the muscles, an alteration that must extend to the nervous ramifications which they receive, and not from a morbid state of the nervous centres; not only is this alteration visible, as we have remarked above, but it seems to us proved by the fact that the muscle is no longer capable of contracting under the direct action of an electric current, — an incapacity which would not be presented were it in a healthy state. The same remark applies to other cases of paralyses by intoxication, which beside present analogous symptoms, and may be treated in

* M. Duchenne understands by nervous gymnastics, the repeated exercise of voluntary contractility, so long as this is possible to the patient, who must assist in this by all necessary means.

the same manner. However it might be possible that, in all these cases, the alteration of the muscles would not be a direct effect of the action of poisons; but the indirect result of their action upon the nerves.

We say as much of *rheumatismal* paralyses, which are evidently due to a modification of the muscular tissue, such that the muscle is no longer able to contract. This modification is manifested by the abolition of movement, which is the consequence of the very acute pain that a muscle, or a system of muscles, undergoes as the result of a cooling; for example, — pain, which increases by touch, and by the least movement, which renders these latter impossible. It commonly happens that, when by the aid of divers therapeutic agents, we have become master of the pain, the voluntary movement returns into the muscle that had lost it; but sometimes it does not appear again: it is to this momentary or permanent abolition of muscular contraction, that the name of rheumatismal paralysis has been given; it is able to affect all the muscles of the body. M. Duchenne has found that the muscles thus paralyzed retain their electric contractility even when they have lost voluntary movement. It is by employing equally cutaneous and muscular electrization, and by acting successively upon each of the paralyzed muscles in particular, that we very generally succeed in obtaining a cure. The cases that M. Duchenne has been called upon to treat are rheumatismal paralyses of the fore-arm.

Among rheumatismal paralyses, facial hemiplexia and rigidity, which is sometimes the consequence of it, are amongst those that M. Duchenne has most studied. We have already seen that this affection is due to the paralysis of the seventh pair, the various degrees of which may be appreciated very exactly by the more or less decided weakening of the electro-muscular rigidity. In the cases in which this weakening is almost null, the cure is very prompt; and although it may sometimes take place spontaneously, it is better however, in order to obtain it more surely and more rapidly, to restore it by localised electrization. When rheumatismal paralysis of the face is such that the paralyzed muscles no

longer contract, which constitutes its second degree, the preceding degree being the first, it opposes in general a great resistance to therapeutic agents; however it yields to localised electrization, as M. Duchenne has often proved; only it requires in general from three to six months of treatment; and voluntary contractility cannot always be completely brought back to its normal state. Unfortunately, rigidity of the muscles of the face is a very frequent termination of this paralysis; and it is of importance to make a diagnosis of it in time, which is not always an easy matter; for its appearance may counter-indicate the employment of localised electrization, or may require that its mode of application may be modified. One of the signs of an approaching rigidity is, first, the appearance of a spasm in a paralyzed muscle of the face, under the influence of an artificial excitation; it is likewise, in the absence of this spasm, the too rapid return, and before its time, of tonicity in a completely paralyzed muscle; it is likewise certain changes in the habitual expression of the physiognomy, which a tolerably long experience of affections of this kind teaches one to discern. Consequently, in the treatment of rheumatismal paralysis of the seventh pair, M. Duchenne is disposed to believe that it would be better when this paralysis is at its second degree, that is to say, when the muscles have completely lost their electric contractility, not to apply localised electricity immediately, as may be done with advantage when the paralysis is at its first degree only; however, he still has some doubts in this respect, and thinks that his assertion must not be considered as general. With regard to the mode of the application of the electricity, M. Duchenne prefers to localise the excitation in each of the paralyzed muscles, rather than to act indirectly upon them, by electrizing the nerve of the seventh pair; which, besides, is in accordance with the general observation that paralyses of motion are more happily influenced by the direct excitation of the muscular fibre than by the intervention of the excitation of the nerve by which it is animated.* In order to

* We shall see that the reverse is the case for paralyses of sensation.

restore muscular tonicity and voluntary contractility, which is the object in rheumatismal hemiplexia of the face, we must act with currents having rapid intermittences; but when the return of the muscular tonicity, that ordinarily precedes the appearance of voluntary movements, has taken place, the intermittences must be made at wider intervals, so that there may not be more than from one to four per second, especially when we see the precursory symptoms of rigidity manifested in a muscle. We may, however, continue to apply localised electrization, but with prudence and with intermittences far apart, to muscles threatened with rigidity, and even already in a state of rigidity. In this latter case, we must join to the electric treatment the direct elongation of the muscle, either by making the patients themselves exert tractions on the lips, the cheeks, the eyelids, in the direction of the fibres; or by making them place between the cheek and the jaws as large a ball as possible, so as greatly to distend the cheek, and consequently the rigid muscles.

There are some other varieties of paralysis besides those of which we have spoken, which, although less frequent, would deserve however to attract our attention, if we were not obliged to restrict ourselves. We shall mention in particular the general paralysis of idiots, which we sometimes run the risk of confounding, either with a chronic softening of the brain, or with a malady of the marrow; the action of the electric current may be employed, not as a therapeutic means, for it does not appear that it can be efficacious, but as a means of diagnostic; for the question under consideration is a chronic softening of the upper part of the spinal marrow, electro-muscular contractility is abolished, or at least is notably diminished. We may mention also the paralysis known under the name of *cramp of writers*, which consists of an incomplete paralysis of the fingers of persons who pass a portion of their lives in writing, whence there results to them the impossibility of continuing to exercise their profession. When this paralysis is quite local, it is very well cured by the application of electric currents. M. A. Bec-

querel quotes the case of a man, the five fingers of whose right hand had become gradually paralyzed, and who at the end of a month was entirely cured, by an electric treatment produced with the magneto-electric machine of MM. Breton. But the paralysis in question is not always local; it sometimes has its origin in an affection of the nervous centre; in this case, electricity, far from exerting a good influence is rather hnrtful.

The paralyses of movement in the muscles of organic life have, on the part of M. Duchenne, been the subject of a great number of attempts of curing by electricity; they are, in particular, those of the intestines, the rectum, and the bladder, for which these trials have been sometimes attempted with success, at other times without favourable results; it very frequently happens that, in the latter case, it is the paralysis of the muscle of the abdomen which is the real cause of the malady; also localised electrization, conveyed to these muscles, is the most suitable treatment. When the object is to cause electric currents to arrive at determinate points in the interior of one of the viscera, M. Duchenne employs for conductors metallic probes, insulated by an envelope of caoutchouc, except at their extremity, where the metal is bare, which prevents the currents passing, save by the points in contact with this extremity. Loss of speech, produced by the paralysis of the muscles of the larynx, has been likewise cured in some cases by the application of localised electricity, provided that this loss of speech was independent of all organic lesion, and not symptomatic of another malady. When muscular electrization applied to the anterior part of the neck is not sufficient, it is necessary to add to it cutaneous electrization, practised for four or five seconds on the level of the larynx; and, in general, good effects are obtained from this. However, in all the preceding cases, local paralyses are most commonly only symptoms of other much more serious maladies; and then, unfortunately, electricity is almost always powerless.

We may compare with the paralysis of the muscles of organic life that of the diaphragm, of which M. Duchenne

has made a very special study; this disease, which appears to be extremely rare, consists in an alteration of the regular movements of the chest and the abdomen during inspiration and expiration, which produces a short respiration, insufficient to the wants of the voice; this is not a fatal disease of itself, because respiration is not completely prevented; but the most simple bronchitis is able to occasion death by suffocation, expectoration being difficult and even impossible. The treatment pointed out by M. Duchenne is the electrization of the diaphragm by the intervention of the phrenic nerves, which produce a veritable artificial respiration, which may also be obtained by means of cutaneous electrization, effected rapidly upon different parts of the body. These two methods of obtaining an artificial respiration may be likewise turned to useful account, in the cases in which the respiratory muscles are half paralysed, as in certain cases of poisoning, violent fevers, &c.

Paralyses of sensation, like those of motion, have been treated by electricity, as we have already remarked in the first two Sections of this Chapter. Prof. Wartmann had already, long ago, pointed out the employment of induction currents, as calculated to arouse sensibility in cases of anæsthesia produced by the inspiration of ether, when this anæsthesia, carried too far, would run the risk of being mortal *; but we have to occupy ourselves there with the paralyses of sensation that arise from a sickly state, and which consist essentially in a disturbance of sensibility, either simply cutaneous or also muscular. This disturbance is not simply an anæsthesia, that is to say, a privation of sensibility, but it is also sometimes a hyperæsthesia, that is to say, on the contrary, an exaggeration of sensibility. In this latter case, if the pathological state does not arise from an affection of

* The effect of ether, chloroform, and other anæsthetic agents, is probably due to the fact that the blood, by conveying to the nerves the very divided particles of these volatile liquids, determines in them a species of inertia, which deprives them of the susceptibility of polarizing as they ought to do when they are transmitting either impressions from the brain to the periphery, or sensations from the periphery to the centre. It would be interesting that physiologists should try the direct action upon the nerves of anæsthetic agents, I am however ignorant whether these trials have been made.

the nervous centres, cutaneous electrisation may be employed, by practising upon the dry skin an energetic electric fustigation, or by moving solid metal conductors about the suffering region, at the same time that the apparatus is acting with very rapid intermittences; the intensity of the current is proportioned to the degree of energy and the excitability of the patient; the operation must last from two to five minutes. This mode of treatment unfortunately produces often only a momentary relief; but there are cases however of a complete cure. Cutaneous electrization triumphs more easily over anæsthesia: the employment of the electric hand is sufficient for the cure of cutaneous anæsthesia of the face; but for the neck, the trunk, and the limbs, solid metallic exciters are necessary; and even if the skin has completely lost its sensibility, the employment of wires, the action of which is deeper, is necessary. These wires are placed upon the part of the skin affected by anæsthesia, causing the apparatus to act with its maximum of force, and with rapid intermittences; if the therapeutic action is immediate, as is the ordinary case, the invalid suffers, in the points excited, a tickling sensation, accompanied by a redness, and followed by a slight sensation of burning, which goes on increasing rapidly, and which soon becomes intolerable. The same operation is recommenced upon the neighbouring parts until the paralysis of the skin has been thus modified to a certain extent. Then the wires, which have become insupportable to the invalid, are replaced by solid metal exciters, care being taken to diminish the intensity of the current in proportion as sensibility reappears. In general, the action of cutaneous electrization is almost always limited to the points of the skin which are placed in contact with the exciters; it sometimes, but very rarely, happens, that sensibility returns in the whole extent of the surface of the skin, even when we have confined ourselves to exciting more or less violently a single point of this surface. Although relapses very frequently take place, nevertheless, cutaneous anæsthesia is the more surely cured, as the electric excitation has been renewed a greater number

of times. It is especially, when seated in the hands and in the feet, that cutaneous anæsthesia is serious as to its consequences; but cutaneous electrization and that of the collateral nerves are generally successful. Nevertheless want of success in the cure of cases of anæsthesia, by the electric method, is also of very frequent occurrence; it is possible that this is due to the fact that in these cases they are only the symptoms of other diseases. It is probable that cutaneous hyperæsthesia and anæsthesia, properly so called, and curable, arise from a sickly state of the nervous tufts; and we can conceive the action of electricity, which tends to re-establish these tufts in their normal state, by being directly applied to the points of the skin on which the extremities of these filaments of the nerves abut. Muscular hyperæsthesia and anæsthesia are no less frequent than those of the skin. The muscles, like all the organs which receive the sensitive or mixed nervous filaments emanating from the cephalo-rachidian centre, enjoy a sensibility which they derive from these nervous filaments and from their communication with the encephali. This sensibility, although less acute than that of the skin, is however susceptible, like the latter, of increase and diminution, and even of abolition. Cutaneous electrization, when applied to the painful spot, excites an acute disturbing pain, which is not long in modifying or in dissipating the muscular hyperæsthesia; however, it presents more resistance to this mode of treatment than cutaneous hyperæsthesia; the question here is hysterical muscular hyperæsthesia; with regard to that which constitutes muscular rheumatism, such as lumbago, a muscular pain of the shoulder and the neck, it rapidly disappears under the action of cutaneous electrization; one or two electric fustigations are most commonly sufficient. The rapid cure obtained in the period of acuity, by simple electro-cutaneous excitations, proves well that muscular rheumatism is not inflammatory, but that it is due to a neuralgia which has its seat in the muscles. When muscular rheumatism is complicated with paralysis, which sometimes happens, it is necessary to commence, before applying

muscular electrization, by applying cutaneous electrization, in order to cause the pain to disappear as much as possible; it is especially in the muscles of the arm and shoulder that this complication arises. If rigidity accompanies muscular rheumatism, electro-cutaneous excitation may cause it to disappear at the same time as does the pain; M. Duchenne considers that it may be applied to cricks in the neck by a rheumatismal cause, even during the period of acuity. When the rigidity of a muscle has arrived at a mean period between the acute and the chronic state, and the muscle consequently has not yet contracted, we may hope to obtain its cure by placing the antagonistic muscles in a state of artificial rigidity, by means of localised electrization applied with rapid intermittences; this treatment is particularly successful, especially in cricks of the neck and shoulders. The muscles, whose tonic power is thus increased artificially, act like the orthopædic apparatus that are placed upon one of the lower limbs, in order to oppose an occasional malformation by a muscular rigidity. M. Duchenne concludes, from a very great number of observations, that crick, produced by rheumatismal rigidity of the rhomboid and the rotatory muscles of the head, may be advantageously combated by electrization, with rapid intermittences, of the muscles antagonistic to those which are rigid.

If, instead of being increased, muscular sensibility is diminished or abolished, it is necessary, as in the case of cutaneous anæsthesia, to commence by treating the paralysis of movement, with which the two kinds of anæsthesia most commonly co-exist, which likewise commonly disappear with this paralysis. But in the cases of hysteria, the two anæsthesias may either go together or be isolated; however, deep muscular anæsthesia is rarely alone: it more frequently accompanies either muscular paralysis or cutaneous anæsthesia; it is therefore treated at the same time and in the same manner as the other two. When by chance it is alone, or exists with muscular paralysis, it is necessary to act with energetic electric currents, and to make them penetrate by the ordinary method into the thickness itself of the muscles.

It is to a species of muscular anæsthesia that the abolition is due of that special sensibility to which, as we have already said, M. Duchenne has given the name of *muscular conscience*. The individuals in whom this faculty is wanting have no longer the conscience of the extent of their movements, of weight, of resistance, &c. It sometimes happens to them, when the exercise of sight has been momentarily taken from them, to lose the faculty of exercising the slightest voluntary movements. M. Duchenne, in this case, applies localized electricity, which re-establishes muscular conscience, at the same time that it causes the anæsthesia to disappear in the muscles that are attacked by it.

The neuralgias, of which we made mention in connection with muscular rheumatism, which is very probably one form of them, deserve the more to attract our attention for a moment, since they are one of the categories of morbid affections, to the cure of which electricity has for a long time been applied. Nothing is so little known as the cause of neuralgias; very frequently they may be occasioned by some small tumour, some muscular disorder, which acts upon the nerve and produces pain. But we are here speaking only of those which have their seat in the nerve itself. If we are permitted to put forth an opinion, perhaps very venturesome, upon this subject, we might be disposed to see in neuralgias, properly so called, a disturbance in the natural electric state of the nerve, in such sort that there might be a conflict between its abnormal arrangement and the regular nervous action. Now, to re-establish, if it is possible, the predominant influence of this latter action would be the most sure means of combating neuralgia; and for this purpose, the employment of electricity would seem to be indicated. The form under which the electrization should take place would not be a matter of indifference; it would first be necessary to endeavour to make the electric current penetrate directly into the nerves; it would then be of importance to impart to these currents such a direction that the nerve might be in an electric state, similar to that which it possesses in the normal state. Now, medical practice indicates the necessity of

having regard to the two points that we have just been noticing. M. Magendie was the first who conceived the idea of causing the current to reach the nerves themselves in the treatment of neuralgias of the fifth pair, by introducing two platinum needles, one at the origin of the nerve, or at least in its immediate vicinity, the other towards its termination. The continuous current of a battery, at first rather strong, but whose power might be gradually increased a little, passed from one needle to the other by traversing the nerve and all its divisions. After the cessation of the pain, which did not generally take place until after several successive sittings, the needles were not immediately withdrawn; but the patient was made to perform some of the movements which generally bring on neuralgia, in order to be quite sure that it had disappeared. Although M. Magendie has also employed induction currents, Mr. James, who has written a work on *the treatment of neuralgias by electricity*, remarks that, in order to succeed, they are obliged frequently to make use of a veritable continuous current. M. A. Becquerel characterizes, under the name of substitutive or disturbing method this mode of application of electric currents. He has himself obtained very satisfactory results by a method, which he has termed hyposthenisant, and which seems to me to have many relations to the preceding. It also consists in causing a direct and continuous current of a certain intensity to circulate in the nerve; but it is indispensable that the positive pole of the battery, which produces this current, should be placed towards the nervous centre, and the negative pole at the periphery, so that the current may be direct, that is to say, may traverse the nerves in the direction of their ramification. If the current is indirect, the therapeutic action would none the less take place; but the pains would be much more acute during the whole of the time that the current was made to circulate in the nerves. M. Becquerel, resting on the experiments of MM. Nobili and Marianini, which we have quoted in the Fourth Part of this Treatise*, thinks that by thus acting upon the nerve, its sensibility, like its mobility, are made torpid momentarily: and this it is which

* Vol. II p. 501.

has led him to give the name of *hyposthenisant* to his method. Although, in order to cause the current to penetrate into the nerve, Magendie's method of electro-puncture may be more sure, nevertheless, M. A. Becquerel, in order to avoid too acute a pain to the patient, more commonly contents himself with two moist sponges for electrodes; the positive one is applied upon the point of the nerve that is nearest to the nervous centre, the negative one is drawn successively over the branches of the nerve that are most in pain. This treatment is, in general, not long: if at the end of twelve or fifteen sittings nothing has been obtained, it is very probable that we shall not succeed. M. A. Becquerel, in this kind of medication, has substituted an induction apparatus without inconvenience for the trough battery; care being taken to have one only of the induction currents always guided in the same direction: and so arranging the electrodes that this direction is such that the positive electricity arrives on the side of the nervous centres, and the negative by the peripliery. It is, moreover, necessary that the intermittences be very rapid; under these conditions induced currents act like continuous currents. Only in the first instance the pain is very acute, and is accompanied by a fibrilline trembling of the muscles placed upon the route of the currents; this pain soon gives place to the sensation of a numbing, which gradually increases, ends by becoming complete and profound, and endures until the end of the application. M. A. Becquerel quotes several interesting cases of the cure that he has obtained by the method that we have just been describing, among others that of a young person, aged nineteen, attacked by a neuralgia which occupied the two super-orbital nerves, and which had a regular course. Commencing at eleven in the morning, it was endurable until four or five in the afternoon, a period from which it increased in intensity until two o'clock in the morning to such a point that the patient could not restrain herself from uttering piercing cries; and that in the moments when the pain was most acute, there were convulsive movements of the forehead and the eyelids. At two o'clock in the morning the pain decreased progressively

until five in the morning, an hour at which sleep arrived; then everything recommenced at eleven o'clock. All remedies had been attempted, but in vain: sulphate of quinine, opium, valerian, morphine blisters, &c. Electric treatment was then applied: the first three days a sitting of ten to fifteen minutes was given at one o'clock, the two electrodes being placed between the two temporal regions during one half of the sitting, and between the two super-orbital nerves during the second half. Each time the pain suddenly disappeared; and the patient suffered no further attack until six o'clock in the evening,—a moment at which it returned. Afterwards, two sittings were had each day, one at one o'clock, the other at six o'clock; and in ten days the cure was complete and absolute.

Besides the method that we have been describing, there has been employed, in the treatment of neuralgias, another devised by M. Duchenne, which is the revulsive method, founded upon cutaneous electrization. We have already mentioned this above, in connection with hyperæsthesias, giving sufficient details upon the manner in which it is practised: according to M. Becquerel, this mode of application of electricity produces anæsthesia of the suffering nerve, by bringing about a derivative pain. We are rather disposed to believe that it is, as we have said, by a direct effect upon the ultimate nervous ramifications that it acts. This mode of treatment, particularly applied by M. Duchenne to sciatic neuralgia, is however susceptible of being employed against every other species of neuralgia. Although it does not always give satisfactory results, there are, nevertheless, particular cases in which it seems more appropriate than the former; the employment of which, however, appears to us more rational and more calculated to bring about a prompt and complete cure.

Among the paralyses of feeling, those of the organs of the senses deserve more particularly to attract our attention; although hitherto we must acknowledge that the employment of electricity in their treatment has not given very satisfactory results.

Magendie was the first who had attempted, by a rational

application of electricity, to treat the complete or incomplete paralysis of sight, that is to say, amaurosis, in its different degrees. It plainly appears that he has obtained some success. However, this mode of treatment has not been generally adopted, which proves that it leaves something to be desired, and that perhaps it is not without inconvenience. We may remark, first, that it would be perfectly useless to employ electricity for the treatment of amauroses connected with a general state, or which arise from a disease of the brain; it is only essential amaurosis, properly so called, that we have some chance of curing by this means. Among these latter, hysterics, being most frequently merely transitory, disappear in general of themselves, or yield to an ordinary medication, such as hydropathy; however, if they are persistent, the employment of electricity may have a good effect. Amauroses, which are accompanied by congestion toward the head, ought not to be treated by electricity — a treatment which must be especially guarded against for those which go with a state of feebleness of the organism. It is rare, even in this case, that when the sight is lost in an absolute manner a cure is obtained; however, Magendie has cured a case of complete amaurosis. The more electricity is employed at a period approximate to the commencement of the malady, the more chance there is of succeeding. The amauroses which are occupying our attention are evidently due to a paralysis of the optic nerve. Thus, the more we reach this nerve directly by electricity, the more shall we operate under good conditions. In this respect electro-puncture, if it did not frighten the patients too much, would be the best mode of application. M. Magendie operated in this way; M. Person likewise, by planting needles in the orbit and even in the sclerotic as far as the vitreous humour, obtained several cases of complete cure: M. Magendie and himself employed continuous currents. These currents are also employed by M. Purkinje, who has remarked that the direction of the current is far from being indifferent; thus, when the amaurosis is at its commencement, and is accompanied by subjective pains, he places the negative electrode as near as possible to the

eye upon which he desires to act, whilst it is the positive electrode which he thus places when the amaurosis commences by a weakening of the sensibility of the retina; the contrary pole to that which is near to the eye being placed at a certain distance, in contact, for example, with the buccal gland.

M. Duchenne cites a case of diplopia, which he succeeded in curing by the current of a very strong battery, by applying the two moist electrodes respectively upon the patient's two eyelids, previously closed. Two successive excitations were given at a second of interval, and with a very strong dose. The patient saw a considerable flame, which caused a sort of dazzling to him; he shook his head, and, opening his eyes, he said: "You have no more than one head; I no longer see double." His cure was complete, and is maintained. M. Duchenne had not been always so fortunate; having one day treated the paralysed muscles of the face, with the current of a battery, he occasioned in the eye of the patient the appearance of a sudden flame (phosphene), which was followed by a considerable disturbance of the sight in this eye—a disturbance which he has not succeeded in causing to disappear. It is this accident which, by demonstrating to M. Duchenne the special action of continuous currents upon the retina, induced him to make the trial that we have first cited, and the result of which was of the most satisfactory character. We have already remarked that in induction currents, which he calls of the first order, that is to say, those which are not extra-currents, M. Duchenne has recognised the property of acting upon the retina. However, M. A. Becquerel advises rather to employ currents of moderate tension, administered with slow intermittences, by applying moist electrodes around the orbits, upon the eyelids themselves; the sittings should be short; a very great number of them are necessary; and we must act in general with many precautions and much patience; the treatment may sometimes last for several months. If moist sponges are not sufficient, electro-puncture, which presents good chances of success, may be tried.

The paralysis of the organs of hearing has been also treated by electricity; but it is evident that here, as for the organ of sight, this mode of treatment can present chances of success, only so long as the seat of the disease is in the auditory nervous system. On this account it is that it must not be applied until after a diagnostic made with much care. However, even after having been satisfied by a rigorous exploration that the mean ear is sound, that all the passages are free, and that consequently the deafness has its seat in the internal ear, it does not follow, as M. Ménière* judiciously remarks that it arises from an actual lesion of the acoustic nerve. There are so many other parts, so many tissues in the internal ear, the lesion of which may be a cause of deafness, that the conclusion which we have just pointed out might frequently, indeed, be hazarded. But should the deafness be nervous, M. Ménière, as the result of a great number of trials, varied in many manners, conceives that induction currents have no efficacy in the treatment of this deafness, if it is essential, and not symptomatic, as that which is observed in hysterics—a case in which almost all therapeutic means possess an equal success.

Notwithstanding these discouraging results, supported by an authority too respectable for us not to place full confidence in them, we see that there are cases obstinate to other curative means, in which the employment of electricity may be attempted, which, besides, does not present any inconveniences, if it does not offer the advantages that are expected from it. We shall also give, in a few words, the method of operating pointed out by M. Duchenne. He commences by injecting into the external auditory conduit, which is placed vertically by means of the inclination of the head, a quantity of water, sufficient for filling its first half. A wire is plunged into it, which is placed in communication with one of the electrodes of the induced currents, whilst the other is

* We refer for the details to a very interesting article of M. Ménière's, the skilful physician in chief of the Institute of Deaf and Dumb, inserted in the *Treatise of the Applications of Electricity to Therapeutics*, by M. A. Becquerel.

terminated by a moist sponge, thrust into a cylinder which is placed upon the nape of the neck; care must be taken that the wire be not in contact with the membrane of the tympanum, or with the sides of the auditory conduit. We should employ only very feeble currents, appropriated to the delicacy of the organ upon which we are acting. The sensations which the ear undergoes, when it is healthy, are very remarkable; it is first a dry noise, which approaches to that of the beating of the wings of a fly that flies between a window and a curtain, when the intermittences become very rapid. Then to these phenomena of hearing is added a tickling sensation which is communicated to different parts of the tongue; there is likewise a special gustative sensation, which is manifested when the excitation is very energetic. The sensations perceived in the depth of the ear, and in the two anterior thirds of the tongue, plainly announce an excitement of the nerves of the membrane, and of the cord of the tympanum, which seems to give us the hope that an operation, which shakes so deeply the nervous system of the ear, must exercise a happy influence over certain nervous deafnesses. M. Duchenne, in fact, quotes, by the side of an almost equal number of failures, cases in which he has obtained, by electrization of the membrane and of the tympanum, both the cure, as well as an amelioration, in nervous deafnesses, independent of an organic lesion. Quite recently, he has succeeded in curing almost entirely a child, affected with a congenital deaf-and-dumbness, of the kind of those which have hitherto been considered as incurable. This case, which is the first of this kind, is of an immense interest; if it is not the effect of an illusion, if in particular he repeated it, it would demonstrate that congenital deaf-dumbness, under the influence of the electric excitation of the internal ear, may be, if not completely cured, at least considerably ameliorated; it is by operating upon the internal ear, according to the mode that we have described above, that M. Duchenne obtained this unexpected result.

With regard to smell and taste, the attempts that have been made to restore them by an electric treatment, when

they have been lost, are too few and of too little importance for us to dwell upon them.

Among the diseases, to the treatment of which electricity has been applied with success, we should mention also atrophies; we have already spoken of those that attack the muscles which, by the effect of a paralysis or by any cause whatever, cease to act; we shall not return to this. But there are others to which general causes cannot be assigned, and in which the different parts of the nervous system, the encephali, the spinal marrow, and the nerves, remain in a state of perfect integrity, with this difference, however, that in several among them the anterior roots of the spinal nerves are wasted; it is the posterior roots of these same nerves that alone remain intact. This species of atrophy, designated under the name of progressive, fatty, muscular atrophy, attacks successively, bundle by bundle, fibre by fibre, the muscles subject to the will, leaving intact general and special sensibility, the intellectual and affective faculties, and all the functions of the life of nutrition, other than the nutrition of the muscles. M. Cruveilher, to whom we owe the discovery of the existence in this affection, of the atrophy of the anterior roots of the spinal nerves, as accompanying that of the muscles, recognized two degrees in this latter; in the former the muscle is reduced from the fifth to the tenth, and even to the twentieth of its weight, without alteration of structure, but only with a notable diminution in the intensity of the red coloration; the second degree is then atrophy by fatty transformation. According to M. Duchenne and M. Valerius, the electric sensibility and contractility are diminished, but not abolished, in a muscle attacked by atrophy; later, and even before the muscular fibres are quite wasted, the muscle no longer contracts, however intense the current may be, to which it is subjected; but the sensibility of the sensorial nerves, which had been but little or not at all weakened, still remains. M. A. Becquerel believes that electric contractility endures in the remaining fibres; and that it preserves in them the same degree of energy; but that, as these fibres have considerably

diminished in number, the total contractility of the muscle is notably diminished. When the muscles are the seat of the fatty transformation, the electro-muscular contractility is then altogether annihilated. M. A. Becquerel does not think that, in affections of this kind, electricity may be applied with advantage; this is also the opinion of M. Valerius. M. Duchenne, on the contrary, considers that, so long as the muscles preserve their electric contractility and fibrilline contractions, before the extreme period in which the fatty transformation commences to be produced, he is permitted to hope to save them from complete destruction, and, perhaps, to develop them more or less, in rousing up nutrition in them, by means of localised electrization. It seems to me that the remarkable cases of cure or amelioration quoted by M. Duchenne would prove the truth of his assertion, at least when the fatty muscular atrophy is local, and is the consequence of a forced and continuous work; but it is probable that it would no longer be the same, when the atrophy is general and spontaneous, without an incidental cause. It seems, in fact, to follow, from the cases of cure cited by M. Duchenne, that progressive muscular atrophy is directed exclusively to the muscles which are the most fatigued; and that, when once cured by localised electrization, the mere fact of the return to laborious work occasions relapses.

A very interesting general question is here presented; when, as takes place in the cases with which we are occupied, the atrophy of the anterior roots of the spinal nerves accompanies fatty muscular atrophy, it seems a difficult matter to believe that we are able, even by electricity and by acting only upon them, to cure the muscles to which the nervous influence that gives life to them, and determines nutrition, no longer reaches. M. Duchenne is disposed to believe here, as in the case of M. Cl. Bernard's experiments which we have cited above*, that nervous conductors of a new formation here take the place of the wasted nervous roots, and that

* Vol. III. p. 646 (*ante*).

electricity restores to the muscles the property, for a long time suspended, of being subject, for their nutrition, to the nervous influence which had been arrested or interfered with. This point of view, the justice of which we could not deny, would lead us to admit that electricity would be efficacious only so long as the fundamental cause of the disease, the atrophy of the nervous roots, might already have ceased, or at least have diminished; its action would then consist essentially, as we have already observed in our preliminary remarks, in re-establishing the interrupted relation between the muscles and the last nervous ramifications intended to animate them. The presence of voluntary contractility and electric contractility, which remains in this affection so long as it is curable, seems to M. Duchenne not to be able to be reconciled with the name of atrophic paralysis, which M. Cruveilher has given to it; he is even convinced that, by taking it in time, that is to say by not waiting to act until the muscles no longer fulfil their functions or are entirely destroyed, we may not only arrest the encroaching progress of the disease, but even re-make the fibre, by means of localised electrization. It is probable that the differences of opinion which exist between M. Duchenne and M. A. Becquerel, relatively to the treatment of progressive muscular atrophies, are here due, as happens so frequently, simply to the fact that the cases observed by these two skilful physicians were in no way under the same conditions, both in respect to the origin, as well as in respect to the period, of the disease.

The treatment of progressive fatty muscular atrophy generally requires the employment of apparatus of very great power, and with very rapid intermittences; it is evident that the intensity of the current must be gradually diminished, while still retaining it of considerable power, in proportion as the sensibility of the muscles increases, which was at first obtuse; the duration of each application must not be too prolonged (eight to ten minutes at most). Finally, care must be taken to direct the electric excitation, especially, upon the muscles the employment of which is

most necessary, such as those which are the indispensable agents of respiration and motion.

We have seen that M. Duchenne has not distinguished essential muscular atrophy, which is the consequence of the atrophy of the anterior roots of the rachidian nerves, designated by M. Cruveilher under the name of atrophic paralysis, from that in which there is no lesion of the nerves, and which appears however to us to differ essentially from the former; on the other hand he classes, with justice, under a distinct head, under the name of fatty atrophic paralysis of infancy, the disease, described with great care by M. Rilliet, under the name of the essential paralysis of infancy. M. Duchenne admits in this paralysis two degrees, one in which the electric muscular contractility is intact, the other in which it is, on the other hand, very much enfeebled and even abolished. As we see, muscular electric exploration enables us to distinguish these two degrees, which seem to correspond to two classes of affections, one which follows an acute progress and is terminated by a rapid cure, the other having a longer duration and terminating by atrophy and the fatty transformation of a greater or less number of muscles. The first is, perhaps, a slight peripheric affection, probably of a rheumatismal nature; whilst the second is due, as it appears to me, to some morbid state of a greater or less extensive portion of the spinal marrow: for it closely approximates, by its symptoms and its progress, to paralysis, consecutive to the traumatic lesion of the spinal nerves and of the marrow. The fatty atrophic paralysis of infancy is distinguished from the progressive atrophic paralysis that we have described above, in that, contrary to the latter, it goes on decreasing; which is due to the very different cause of the two affections. M. Duchenne has been much occupied with this disease; he has proved, in a very great number of cases, that localised electricity applied in time may abridge the duration of the paralysis, diminish, if not prevent, the atrophy of the muscles, and perhaps prevent their fatty transformation. He has seen, at a very advanced stage of the disease (after a year and more of duration) the

muscles, that are not fatty, recover their electric contractility, however wasted they may have been. Even when the absence of all electric contractility would make us fear that the muscular tissue had become entirely fatty, we must also try an electric treatment for the possible case, in which there might remain, as has happened, some sound muscular fibres concealed in the substance of the fatty tissue. Localised electricity, by favouring their nutrition, ends by developing them, increasing at once their strength and their extent.

Being compelled to restrict ourselves, we shall not dwell long upon affections, other than those upon which we have spoken, which have likewise been attempted to be treated by electricity; besides this would unfortunately be to register more want of success than success. We have already pointed out Nobili's method, applied by Matteucci for the cure of tetanus; this method, which consists in causing a direct continuous current to pass along the spinal marrow, by introducing the patient gradually into the voltaic circuit in order to avoid muscular contractions, has never been applied but once; the patient appeared comforted, but the wounds that had occasioned the tetanus were too serious for him to be able to survive, so that no positive conclusion could be deduced; besides, as M. Dubois Reymond remarks,—the spinal marrow, being very deeply situated, it would be necessary, in order to act upon it, to employ very intense currents, which, on the other hand, might not be without danger; moreover, it would be necessary to act also directly upon the tetanized muscles themselves.

Convulsions in general have been, likewise, for a long time subjected to electric treatments; it is evident that there is nothing to hope from these treatments for those which are a consequence of any actual lesion whatever of the marrow or the brain; it is, at most, rigidities, accompanied or not by paralysis, which remain after the lesions of the nervous centres are cicatrized, that we may have some hope of curing by the application of electricity, of which we have quoted some examples. With regard to the con-

vulsions of children, that generally take place under the influence of a cerebral excitation, the employment of electricity would not only present no favourable prospects, but might be dangerous, or might create a risk of increasing this excitation. It is not the same with hysterical convulsions and hysterical rigidities, to which the judicious application of electric treatment may be very useful, which indeed it is, as we have seen in the majority of hysterical affections in general. We shall not return to the application, made by M. Remack, of continuous currents to the cure of rigidities, — a cure which he regards as a consequence of a reflex action, and of a special excitation of the nervous centres; this point would deserve a profound examination, for which new observations would still be necessary.

Epilepsy and catalepsy have been, they say, cured by electricity; but these pretended cures, announced from the very first period when the therapeutic action of electricity had been attempted, have never been verified; and attempts have not hitherto been made to renew them. Chorea appears more susceptible of suffering a happy influence from electric medication; some trials attempted by M. A. Becquerel would tend to prove it; unfortunately the number of facts relative to this mode of treatment, for this kind of disease, is very limited; and it would be greatly to be desired that new researches should come and fix the ideas upon this point in a more positive manner.

Asthma and angina pectoris are, also, two sorts of affections for which an electric treatment has been attempted. M. Duchenne states that he has succeeded in curing nervous asthma by cutaneous electrization; but he has not quoted in this respect any positive case, not yet finding his observations sufficiently numerous, and having the intention of pursuing his researches.

Angina pectoris, a disease happily very rare, and which is an affection, probably, of a nervous nature, has been the object of very interesting researches on the part of M. Duchenne. It appears plainly proved, from these researches, that it is independent of organic lesions of the heart, which

are, besides, much more frequent than it is itself, but which it sometimes accompanies. In the opinion of M. Duchenne it is the fit which in angina pectoris almost always kills. It is, therefore, of importance to seek the means of arresting these fits; since a single one may be followed by immediate death, and to prevent their return by checking the disease. It is by applying, during the fit, upon each of the nipples of the patient, the extremity of each of the conducting wires of his induction apparatus, at its maximum of force, that he succeeded in causing the pain of the angina, and the other phenomena that accompany it, to disappear; but the artificial pain was grievous, although instantaneous. Some cutaneous electrizations, practised at intervals very far apart upon the painful points, removed the remnant of the angina, and the patient was enabled to resume his trade of currier. This mode of treatment succeeded almost as well in a second case, quoted by M. Duchenne. Nevertheless, here also a greater number of observations would be necessary, in order to establish, upon a solid basis, the electric treatment, in the case of angina pectoris; although we willingly recognise that, if it is plainly demonstrated that this affection is only a form of neuralgia, this mode of treatment should give satisfactory results.

We should here terminate this long enumeration of the various pathological cases in which the electric treatment has been attempted at different periods and under different forms, if an interesting case, which we again quote, had not just demonstrated to us how this mode of treatment, while still being valuable for the cure of local affections, is powerless, as besides are almost all others, against the morbid principle from which in all cases these affections are derived, when they are only the symptoms of a general sickly state, and not a simple local evil. This case to which we have just made allusion, and which was observed at Geneva by Doctors Coindet and Duval, is relative to a young girl, aged seventeen and a half years, on whose finger a gangrene was manifested, depending upon a momentary stoppage of circu-

lation under hysterical influence. All the fingers of the right hand, with the exception of the thumb, were of a slaty colour as far as the middle of the second joint, cold, and in a completely anæsthetic state; the forefinger and the middle finger were contracted into a demiflexion; all movement was impossible; and the patient suffered acute pains. The radial pulse was altogether insensible; and it was necessary to go up as far as to the middle of the arm, in order to perceive the pulsations of the humeral artery. On the left the same symptoms existed in a less degree; and the pulsation of the radial artery was perceived in it. Electrization having been produced with M. Duchenne's volta-electric apparatus, the young girl, at the end of ten minutes, cried out that she was able to move her fingers, and she moved them; at the same time the pain ceased, the radial pulsations reappeared in the right, and rose to from 92 to 116 per minute; sleep, which had been absent for five nights, reappeared: however, at the end of some hours the pain returned. The same treatment was continued on the following days: after each sitting for electrization the pain ceased, in order, it is true, to return, but after an interval of greater and greater length. The stiffness of the fingers was less firm; the nights were good; the rigidity had disappeared since the first sitting; and the throbbings of the pulse from that time no longer ceased to be perceptible. From the second day there was manifested, after each sitting, an abundant transpiration from the fingers, of a fetid odour. At the end of seven days the colour of the hands had become altogether normal, except at the palmar face of the third joint of the fore-finger and the fourth finger, the epidermis of which was raised, and finally fell within a bath. From that time the local affection ceased to reappear. The accessory treatment had consisted of baths, and purgatives, and diuretics. But notwithstanding this cure, the general health remained bad. There were occasional hysterics; and the young girl became phthisical. We see, however, that the effect of electricity was extremely prompt and incontestably evident; but that, if it is able to cure the local disease, it was not able to modify the distress-

ing state of the general health, which had probably brought about this disease.

We shall not terminate this long Section without insisting anew upon the precautions which are required in the employment of electricity in therapeutics. Electricity, if it does not produce good effects, is not always at least completely innocuous; thus, discharges of Leyden jars, the current of too powerful a battery, and especially the currents of powerful induction apparatus, are able to occasion cerebral and nervous accidents, which it is important to avoid. It is true that these accidents are variable with individuals; but the number of those who are not predisposed to experience them is much less than the number of those who are affected by them. The accidents that may be produced by electricity are very varied; they are, at first, a general state of fatigue, bruising of the limbs, a great nervous susceptibility, sometimes even a cerebral congestion; they are, also, the reappearance of old diseases, such as neuralgias, various nervous accidents, the renewal of cerebral hemorrhages, &c.; they are, again, an increase of the intensity of the chronic diseases, which exist at the moment when the electricity is administered. The existence of similar diseases, when they possess a certain degree of intensity, should make us fear the employment of electricity, even when some momentary amelioration might result from it.

Independently of these general accidents, electricity may, when it is badly applied, or is unseasonably applied, produce grievous local effects. Thus it is that we run a risk when we employ it too soon or employ it too intense, to aggravate or to renew the symptomatic paralyses of diseases of the brain and the marrow. In acute rheumatismal paralyses, the employment of electricity often increases the pains and renders them intolerable, without producing any fundamental good. We shall not insist upon the accidents that may arise from the fact of acting with too powerful doses of electricity, in particular in the treatment of anæsthesias and paralyses of the organs of the senses; we have already given examples of this, when occupied with affections of this class; besides,

it is evident that it is of this therapeutic process as of all others which, salutary when applied in moderate doses, become dangerous when they are exaggerated. In neuralgias, it is rare that electric treatment, whether it take place by the revulsive method of cutaneous electricity, or is produced by acting directly upon the nerves by the hyposthenisant method, produces accidents. It is not the same for convulsive diseases, for which the employment of electricity requires many precautions. There are affections, such in particular as atrophies, for which it is excessively important to know how to apply electricity at the opportune moment; for, just as much as it is able to do good when applied in time, just so much it can be pernicious when applied too late.

Such are some general rules which experience has pointed out; but it is especially to the tact of the physician, to his diagnostic and to his prudence, that we must refer for the direction to be followed in the employment of this therapeutic agent, from which medicine has already derived advantage, but from which, in our opinion, it has still much to hope.*

Indirect Therapeutic Effects of Electricity.

We have already said that we classed under this head the therapeutic effects that are produced by electricity when it acts no longer in virtue of its physiological properties, but in virtue of its chemical or physical properties, and consequently as does every other chemical or physical agent. We shall here speak also of the effects that are due to the action of electricity in general, without our being able to assign exactly to what class of properties they are related; such, for example, as that which consists in restoring the lacteal secretion. Indeed, although the lacteal secretion is a veritable chemical operation, it is very probable that electricity, by provoking it, does not act chemically but rather physiologically, by exciting the nerves which, by leading to the

* We shall not terminate this paragraph without recalling to mind that it is M. Masson to whom we are indebted, as the result of very interesting electro-physiological experiments, for the first idea of the application of induced currents to therapeutics.

mammary glands, determine the secretion. If this influence of electricity were a chemical action, continuous voltaic currents would be much more fitted to provoke it than would discontinuous induced currents; now, experiment has demonstrated the contrary. More than this; attempts have been made to cause the blood to pass, by means of voltaic electricity, through the secretive organs, such as the liver, kidneys, &c., separated from the body of the animal, and consequently deprived of life; and we have never obtained any but the same product, that is to say, an identical liquid, resulting from the electro-chemical decomposition of the blood*; which proves that these organs act in these cases only as simple moist conductors. However, whatever be the mode of the action of electricity, it is none the less certain that it acts in a remarkable manner upon the lacteous secretion, which follows from an observation of M. Aubert's, repeated and verified by M. A. Becquerel upon a young woman of twenty-seven years of age, with whom, as the result of repeated excitements, the lacteous secretion diminished in her right breast, and was almost entirely dried up in her left breast. Induced currents of moderate intensity were applied to this latter breast; they were made to traverse the mammary gland by the aid of electrodes, furnished with moist sponges, placed successively in the different points of the surface of the breast, and so that the current might penetrate into almost all its parts. Three sittings of fifteen minutes each were held; from the first, the flowing of the milk took place in the evening; it thence continued without ceasing, and on the evening of the third day the milk was abundant in the left breast. Since that time the young woman has not ceased to have milk in abundance; and the child, which had suffered a momentary suppression of its nourishment, was promptly re-established, and continued to go on very well.

It would appear that it is not only upon the lacteous secretion that electricity is able to act; M. Luding has, in fact,

* These facts are the results of experiments that M. Macaire and I had made in 1824, and which we have never published.

demonstrated to the Scientific Congress of Vienna, in 1856, that it increases, in general, the quantity of secreted liquids; that it determines, for example, a considerable increase in the secretion of the salivary glands, by being applied methodically upon these glands. This kind of application would appear to us worthy of being studied with care; for it might be capable of rendering important services.

If, as we have said, it is rather to its physiological properties than to its chemical properties that we must refer the effect of electricity upon the secretions, it is no longer the same when the question is the attempts that have been made to employ it on dissolving calculi of the bladder. The first idea of this application belongs to Dr. Harle, of Norwich; but the first trials that have been made of it are due to MM. Prevost and Dumas; they have directed them, not with a view of extracting the calculus, but with a view of destroying the state of aggregation which connects its molecules together; because, when once it becomes friable, it would come out easily. They satisfied themselves in the outset, by applying upon the calculus itself, plunged into water, the platinum wires serving as poles to a very powerful battery, that the calculus was decomposed, or rather was reduced into so fine a powder, that, at the end of a double operation of sixteen hours, the most voluminous fragments were not of the size of a lentil, and might consequently pass through the canal of the ureter—notwithstanding the very compact calculus weighed ninety-two grains before the experiment. The principal point, upon which the researches of MM. Prevost and Dumas were afterwards directed, has been to determine all that concerns the sensibility of the bladder in this kind of operation; in order to know as to what point it would be practicable upon living man. They thought they might be able to conclude, from experiments made upon dogs, that it would be possible to introduce into the bladder the two conductors serving as electrodes to a voltaic current, and to produce in it an abundant chemical decomposition, without wounding this organ, or affecting it in an unfavourable way. But, while still seeing that their method was susceptible of

application, they perceive that it can present no advantage for the extraction of calculi that are not saline compounds, such as alkaline phosphates, but that are composed entirely, or in a large proportion, of uric acid. It would therefore be essential, beforehand, to be satisfied as to the nature of the calculi. With regard to the liquid to be introduced into the bladder, they found that there was an advantage, in order to facilitate the solution of the calculus, to substitute for water a solution of nitrate of potash. This has been proved more recently, by a series of experiments, by M. Bonnet, surgeon-in-chief of the Hotel-Dieu, at Lyon. He placed successively several calculi, of different natures, between two platinum electrodes, plunging them into a solution of nitrate of potash ($60\frac{1}{4}$ grains in 4 oz. of water); and he succeeded in destroying them partially, by causing them to be traversed by the current for a greater or less length of time. Calculi of oxalate of lime are the only ones that have resisted the action; the others dissolve more or less rapidly: the most prompt effect has been obtained upon an ammoniaco-magnesian calculus. However, the reactions are in general feeble and slow, which renders the operation more difficult upon the living subject; however, the point that M. Bonnet has solved in a satisfactory manner, is the power to convey acids and alkalies to urinary calculi by means of the electro-chemical decomposition of a saline solution, without the powerful reagents being diffused in the urine that is contained in the bladder. Dr. Bence Jones has taken up this subject, which he has enriched with new and interesting observations upon the solution of calculi, by means of the voltaic current; he found, after many trials, that a more or less concentrated solution of nitrate of potash was, in almost all cases, the liquid in which it was most advantageous to plunge the calculus, whatever its nature might be, in order to obtain a prompt and good result; he even succeeded in dissolving very completely calculi of oxalate of lime, provided they contain also phosphates, whilst if they contain urates, and especially if they are only oxalates, their solution is much more difficult.

Notwithstanding all the experiments that we have just been reporting, the solution of calculi in the bladder itself has not yet been attempted, or, at least, if it has been, of which we are not aware, the results of the operation have not been fortunate; since, for the treatment of this class of maladies, we have always the operation of lithotrity, which is now so remarkably improved. This negative result would not astonish us; for, by introducing into the bladder first a solution of nitrate of potash, and then the electrodes, it seems to us that the current must act much more upon the nitrate than upon the calculus; and by supposing that we act upon the calculus indirectly, that is to say by the effect of the nitric acid and potash, liberated respectively at the two electrodes in contact with the calculus, we think that the presence of these two bodies in the bladder could not be innocuous. Neither would the circulation of an electric current, as powerful as that which is necessary, be without danger.

Another therapeuto-chemical application of electricity is relative to the extraction of metals introduced into and remaining in the organism, whether they may have been taken under the form of remedies, or by absorption in the arts and trades which require their employment. To M. Poey we are indebted for the idea of this application, which he has realised, by plunging the patient up to the neck in a metallic bath, insulated from the ground; or he is stretched horizontally upon a wooden bench, the whole length of his body, which is thus situated so as not to be in immediate contact with the metal of the bath. The water is acidulated with nitric or hydrochloric acid for the extraction of mercury, silver, or gold; and with sulphuric acid, for the extraction of lead; the metal of the bath is placed in contact with the negative pole of the battery, and the patient is made to hold the positive poles, sometimes with the right hand, at other times with the left. According to M. Poey, the electric current, by traversing the body which is in the bath, draws with it the metallic particles that are found in it, and deposits them upon the metal of the bath. He affirms that he

has found traces of mercury and lead in the liquid, after having subjected persons to this treatment, in whom he knew beforehand that these two metals ought to be found. We confess, with pain, that we have many doubts as to the reality of the mode of treatment; first, we do not conceive how the electric current can convey into the liquid of the bath metallic molecules, which, according to the laws of electro-chemical decomposition, ought to be deposited only upon the metallic surface of the electrodes. Moreover, it appears to us difficult that this circuit, circulating in the whole of the organism, should go and pass exactly into the points of the body in which the metals that we are desirous of extracting exist in so small a quantity. The subject, therefore, in our opinion, requires being studied anew, being made the object of numerous and accurate experiments, which is not impossible.

The employment of electricity for producing the resolution of tumours, and in particular of those which result from the swelling of the glands, has been attempted on several occasions.* They have sometimes confined themselves to acting externally, by means of cutaneous electrization, which, at bottom, as we have already had occasion to remark, is only a stimulant of the skin, of the same kind as so many others. M. Boulu, from the year 1853, endeavoured to cause electric excitation to penetrate into the substance itself of the tumours, by acting at the same time upon the whole of its surface, and by cutting it at its circumference, so as to insulate it from the neighbouring particles, and to confine the action of the currents as much as possible to the affected tissues. He causes the currents to arrive by means of two semi-discs of metal, with a surface granulated or furnished with blunt points, fixed to plates of ivory, so as not to be in electric communication, and each receiving one of the conducting wires of the apparatus. The application of the discs upon the skin is made with some degree of strength; we act

* Dr. Despine d'Aix has remarked that electricity, such as is drawn simply from an electric machine under the form of sparks, is valuable as a helping means for curing ring-worms, which are being at the same time treated with mineral waters.

thus at the same time in the substance of the tumour and upon its surface. We may also cause fine platinum needles to penetrate into the tumour, which serve as electrodes to the currents, according to the method of an acupuncture. M. Boulu quotes a very great number of cases in which, by operating according to the methods pointed out with induction currents, he has caused to disappear, or to be considerably reduced, both lymphatic tumours as well as glandular enlargements. The effect of electricity cannot here be purely a chemical effect; it is rather an exciting effect, comparable to the other kinds of excitation that are employed in the treatment of maladies of this class. Electric excitation rouses the circulation; gives life again to the tissues; in a word, tends to replace them in their normal state. And although it here produces a result opposite, apparently, to that which it gives in the cure of atrophies, yet it acts by the same principle, and not in virtue of an electro-chemical or electro-calorific dissolving action. Besides, M. A. Becquerel is not disposed to believe, before some few fresh facts shall have demonstrated it, in the efficacy of electric treatment in cervical tumours, at least in all; for, if it is possible to obtain some good results by this treatment when the subject is tumours arising from a chronic inflammation of the glands (*chronic adenite*), it is not the same when the tumours are formed by the tuberculous degeneracy of the glands.

The treatment of aneurisms by electricity, of which we have already said a word or two in the Second Section, presents more chances of success. It is founded upon the property which is possessed by the blood, when traversed by an electric current, of coagulating at the positive electrode; as likewise takes place with albumen, probably by the secondary effect of an acid liberated at this electrode, in the decomposition of a salt which is contained in the blood and in albumen. M. Petrequin, as we have already said, is the first who met with success, and who justly attributes it to the decomposing action of the battery, thus indicating that it is necessary to employ a continuous current, produced by a battery composed of numerous pairs, but feebly charged. The current is made

to penetrate into the aneurismal tumours by means of platinum needles that are planted into it; we may confine ourselves to planting in only the needle that serves as the positive electrode, and to applying the negative electrode, under the form of a plate, upon the skin. It is necessary that this positive needle should penetrate to the centre of the tumour, and that the negative metal plate should be placed at its extremity. A trough battery of twenty pairs, feebly charged, is sufficient for producing the current: the duration of the sitting should be half-an-hour. The method that we have just been describing has been employed with success in a very great number of cases; we ought, however, to remark that it is frequently very painful, and that it is not free from some inconveniences which have the power of causing accidents, such as inflammation of the edges of the puncture, as well as their ulceration and the production of small scars along the course of these punctures. It is also particularly necessary to apply it to the numerous aneurisms, the special situation of which withdraws them from direct impression, and even from ligature. We may add, that if good results are frequently produced in the treatment of traumatic aneurisms of the elbow, we must not disguise from ourselves that these aneurisms easily yield to many treatments founded upon other methods.

It only remains for us to speak, in addition, of one of the indirect therapeutic effects of electricity, which have hitherto been employed in medical practice. It is that which, being founded upon the calorific properties of the electric current, is designated under the name of *galvano-caustic.*

We are aware that cauterization is an operation the object of which is the *ustion* or *scarification* of organized parts; it is distinguished into *actual* and *potential*, according as it is practised with fire or with caustics. Cauterization is *direct* when it is practised upon the place itself of the disease; and *indirect*, or revulsive, when it is executed upon healthy tissues, more or less distant from the disease, in order to obtain a powerful effect of revulsion or derivation. The application of cauteries to the nape of the neck in cases of

chronic encephalites, that of a moxa in the course of a nervous cord attacked with a stubborn neuralgia, that of a seton in the arm, enter into this class of cauterization. With regard to direct cauterization, it is *destructive* when accomplished with a view to the destruction of a tumour, or of a membrane; it is simply *modificative* when used merely for modifying the vitality of the tissues, in order to change the state of the parts upon which it is made to act; as, for example, when we produce the slight touch of a wound of an inflamed mucous membrane with lunar caustic. The therapeutic agents that have been employed for producing cauterization are extremely numerous. We may class them under two principal heads, namely, the agents of cauterization that produce the mortification of the tissues by the caloric with which they are endowed, and those which mortify them by acting chemically upon them. The former, although much less numerous than the latter, are, however, of different kinds; they are metals (iron and steel are more particularly employed) which are highly heated * in a glowing brazier, and to which different forms are given according to the particular end that we have in view; these are moxas, that is to say, an inflammable substance, or layer of carded cotton, for example, of a cylindrical form, which is placed upon the part of the body that we desire to cauterize, and the top of which is set on fire, care being taken to allow it to burn to its entire consumption; finally, they are sometimes the solar rays collected into a single focus by means of one or of several lenses; sometimes also boiling water or oil is employed; but now, when a powerful cauterization is not desired to be produced, it is preferred to bring near to the seat of the disease either an ignited coal or a plate of red-hot iron, to the distance necessary for obtaining the heat that is desired.

Cauterization by incandescent metals being the one most in use, the idea has been conceived of employing electric currents for producing this heating. Dr. Fabre Palaprat

* The ancients were in the habit of employing irons slightly heated; this practice has been abandoned, seeing that it is much better only to employ excessively hot cauteries, which present the red-white coloration, because they make the patient suffer much less than if they were merely red.

was the first who employed a platinum wire, heated by a voltaic battery, in order to produce moxas. A long time after, in 1845, M. Heider employed the same method, according to the advice of Professor Steinheil, for cauterizing the dental nerves when painfully affected. In 1846, M. Crusell, of St. Petersburg, conceived the idea of cutting and cauterizing the tissues, by means of a wire, or a thin plate of platinum, rendered incandescent by a powerful electric current, by making them act after the fashion of a saw, by means of a backward and forward motion. This mode of cauterization was soon diffused in England; and Mr. J. Marshall made it the subject of numerous experiments, first upon corpses and upon animals, and then upon patients, after having proved the possibility of thus cauterizing the tissues. In this manner he succeeded in curing a fistula of the cheek, by means of a platinum wire one fiftieth of an inch in diameter, rendered powerfully incandescent by the electric current; to this he had given the form of a handle, which was introduced into the cavity of the fistulous sinus; subsequently he adopted the same process for destroying other fistulas, tumours of small volume, and for cauterizing wounds, &c. M. Nélaton, from the year 1850, has made the application of it to the cure of erectile sub-cutaneous tumours, which permits of destroying these tumours, while preserving the skin. Dr. Amusat, jun., by means of a platinum wire about one fiftieth of an inch in diameter, and five or six inches in length, entirely heated by the current of a Bunsen's battery, was likewise able to cauterize, both exteriorly as well as interiorly, several important organs, and to cause the removal of cancerous tumours; he likewise employed thin plates or ribbons of platinum, which he caused to be heated in the same manner, and to which, as to the wires, he imparted a backward and forward motion, as Crusell had done, in order to produce the section of the tissues.

Such, in substance, are the various attempts, more or less happy, of galvano-caustic, that had been tried, when, in 1855, an important work upon this subject, by Dr. Middeldorpff, of

Breslau, appeared. The instruments that he employed, are designated by him under the names of *galvanic cauteries, galvanic porte-ligature, galvanic setons.*

The *galvanic cautery* (figs. 439—441), now commonly used in Germany for cauterizing or dividing the tissues, is composed of a wooden handle of a certain size, cut longitudinally into two equal parts, fastened by a ferule at each extremity; this handle is traversed in its entire length by two metallic

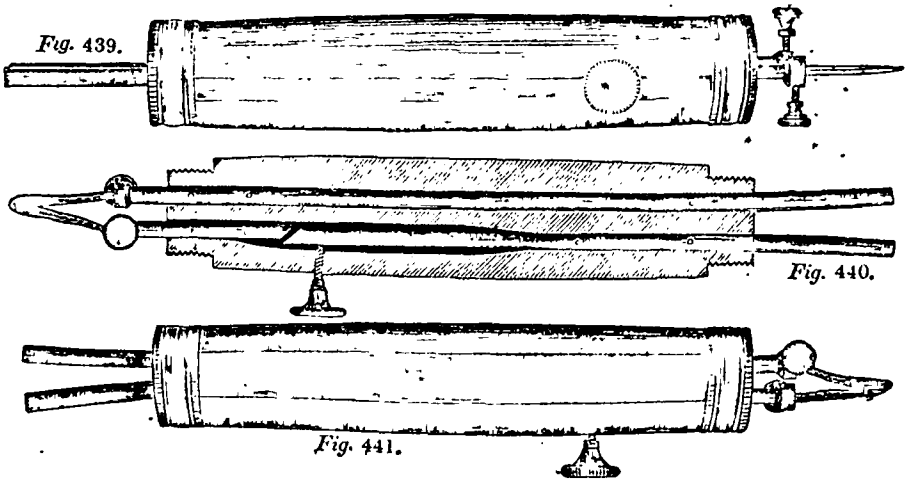

Fig. 439.

Fig. 440.

Fig. 441.

rods of gilt copper, opened at their extremities in order to receive the conducting wire of the electric current; and, on the other hand, the ribbon or wire of platinum, $1\frac{1}{8}$in. in length and $\frac{1}{25}$in. in diameter, intended to become incandescent, and to which the rounded form may be given, or rather that of a bird's beak, according as we desire to use it for cauterizing flat surfaces, or to make incisions in fistulous passages. The firm position of the wires thus fitted is maintained by binding screws. One of the copper rods that traverse the handle is divided, and one of its two portions tends to separate from the other when it is at liberty, thanks to the width, in this spot, of the groove in which it is lodged. When we desire to establish the continuity of its two fragments, a binding screw serves to bring about their contact. With this instrument we are enabled to

direct the platinum wire upon the very place that we desire to cauterize, to render it incandescent immediately afterwards, and then to turn to useful account when cold, in consequence of the arrangement of this rod, which enables us to interrupt the electric current when we desire it. Figures 439 and 441 represent this instrument seen in profile and in front; figure 440 represents it with half of the handle removed, in order to expose the conductors that traverse it.

The *galvanic porte-ligature* consists of wires, that are made to pass, either in tubes of glass or of metal and good conducting tubes, but insulated from each other; the cutting handle is made to project beyond the extremity of the tube; the wires, that pass through the tubes, enable us to give to the terminal handle the volume and extent that are desired.

Galvanic setons are platinum wires of different thicknesses, that are guided by means of straight or curved needles through canals or tissues, in which the object in view is to develope an inflammatory work.

The advantages of galvano-caustic, according to M. Middeldorpff, are the absence of hemorrhage, the rapidity and energy of action, the exact limitation of the effects of the operation, the possibility of burning and cutting deeply-seated parts, which are absolutely inaccessible to every cutting instrument; finally the production of fleshy pimples of a good character. The number of cases to which this treatment is applicable, according to the German doctor, would be very considerable. Among others there would be hemorrhages, which it enables us to arrest in situations into which red-hot iron cannot penetrate; neuralgias, in which it is desirable either to destroy the nerve (as for the dental nerve), or to cauterize certain parts of the surface of the body (as in the case of sciatica); certain paralyses, the gangrene of ulcerations, cancers, but especially fistulas, of which several examples of cure are quoted. Several other cases are also enumerated, such as those of vascular tumours, polypi of different kinds, the removal of which is favoured by galvano-caustic, by rendering it possible in places where the ordinary instruments are unable to

penetrate; amputations even may be accomplished by this method, by employing a very intense electric current, which powerfully heats the wire or plate of platinum. Thus they have been able to accomplish the very complete section of a second finger, by incandescent ligature, which was adhering by a bony soldering to the right thumb of a child six months old, below the metacarpo-phalangian articulation; not only was the section of the soft parts thus accomplished, but also of the bone, the volume of which equalled that of a pigeon's feather; the infant was rapidly cured.

Without dwelling upon all the cases which M. Middeldorpff points out as being susceptible of being treated by galvano-caustic, and while still recognizing that there is exaggeration in this respect, we think that this new mode of cauterization presents certain unquestionable advantages. Without doubt, there are cases in which it is inferior to red-hot iron or to caustics, seeing that it can sometimes give rise to hemorrhages, and that frequently it cauterizes the tissues only very superficially; but we must not conclude from these cases, as some authors have occasionally done, that it can only be employed with success when the object is to modify the vitality of the tissues, rather than to destroy them. M. J. Regnauld, to whom we have frequently had occasion to refer in the course of this work, appears to us, as the result of very well conducted observations, to have perfectly well defined the limits within which the employment of electric cautery may be advantageous: at the same time that he has pointed out the conditions which it cannot satisfy, and the circumstances in which its employment presents almost insurmountable difficulties.

The small mass of platinum that we are able to heat by an electric current, except by employing batteries of a power out of proportion to the object that is proposed to be attained, renders the employment of electric cautery impossible, whenever the object in view is to destroy voluminous tissues. It seems, it is true, that the platinum wire, constantly traversed by the electric current, does not cool down like an ordinary cautery heated to whiteness of fire, and that it

may thus compensate, by the continuity of its action, what is wanting to it in regard to the mass. But we must remark that the contact of the tissues, bathed with liquid, prevents the wire arriving at the high temperature that it would possess in the air, and this, not only by withdrawing from it its heat, but by rendering it, by the effect of this cooling, a better conductor, and consequently less susceptible of becoming heated under the action of the current. Certainly it is not a matter of impossibility to raise a platinum wire to a white heat in the substance of tissues gorged with moisture; but we are between two opposite rocks, either not to heat the wire sufficiently, or to run the risk of melting it: this fusion is brought about in the small part of the wire which comes out close to the skin, and which is more heated in proportion as the portion that is plunged into the tissues is more cooled by the contact of the liquids.* Even when the wire, while still becoming greatly heated, would not melt in its entering and exit points, it would only cauterize these points, and not the interior, as we might be disposed to believe. This inconvenience is verified for all the operations in which the platinum wire must remain plunged in the tissues (cauterization of long fistulous passages, the excision and removal of voluminous tumours). M. J. Regnauld, while still not rejecting in an absolute manner, even in these last cases, the employment of electric cauteries, considers that this class of apparatus, the incontestable advantage of which, resulting from their feeble mass, is to be able to raise them to the highest temperatures without having to fear the effects of radiation upon the parts in the vicinity of those that we desire to destroy, possesses a great superiority over the other methods for cauterizations produced upon surfaces of little extent, situated in the neighbourhood of delicate organs, or in the depth of some natural cavities. He likewise believes, according to his experience, that the most sure mode of application consists in successively repeating the contacts of the incandescent stylus, and the parts upon which he operates.

* Vide, for phenomena of this class, Vol. II. p. 244.

We think it useful, in conclusion, to give some details as to the manner of manipulating galvano-caustic, the employment of which, we are convinced, still tends to become more general, for cases at least in which it is evidently superior to the ancient processes. One of the essential points is to be able to heat to whiteness conductors of very variable volume; it would, therefore, be necessary that the operator should have at his disposal batteries of very variable force in themselves. M. Middeldorpff, who employs Grove's batteries, has succeeded in so combining them, that, by means of a commutator, he is able to procure for himself immediately, and at pleasure, a current more or less powerful in intensity and in quantity; and thus to obtain the incandescence of the wire and plates of platinum, of which he has need. We think that great improvement might be introduced into this part of the apparatus, by having a battery of a smaller volume than Grove's battery, of a more convenient manipulation, and of a force sufficiently variable to provide against the wants in question; it would be an interesting subject of research to philosophers to find such a battery as this: we do not think that this would be very difficult, especially in this case, in which the cost price is of little importance. The great advantage of galvano-caustic is, that we can manage electric cauteries with a tranquillity and precision very different from the precipitation hitherto inseparable from cauterization with red-hot iron. Thus, when we desire to cauterize the bottom of a cavity, the instrument, while cold, is introduced slowly, gently; then, when we are quite sure that it is exactly in its place, we press upon the knob of the apparatus (*fig.* 441.) which closes the circuit that had remained open; and immediately afterwards the current passes and cauterization commences: it is arrested by the reverse operation. As we have seen, it is the arrangement of the platinum and its form (sometimes a plate, at other times a wire), which establishes the principal differences between M. Middeldorpff's galvano-caustic instruments. M. Bocca, who has made a very interesting report to the Society of Surgery at Paris upon this subject, describes cases of amputation upon animals, accom-

plished by the cutting handle, which show that, in order to avoid the flow of blood, we must not heat the wire too highly; and that, consequently, it is necessary to operate with a battery of mean force. He quotes, also, three different cases of galvanic cauterization, two of them accomplished by M. Middeldorpff, the third by himself, which have been followed by complete success. According to him this cauterization not only guards against primitive hemorrhages, but it appears also to dispel the chances of consecutive hemorrhage; and it presents, over the employment of red-hot iron, the great superiority of being incomparably less alarming to invalids, by suppressing the terrible apparatus of ordinary cauterization.

As we see, practitioners are not yet completely agreed as to the scope of galvano-caustic; some restrict it to a small number of cases, whilst others greatly extend the use of it. For ourselves, we attribute to this operative process very great future prospects, on account of its simplicity and its convenience; but we also consider that it must not be employed except with extreme caution, especially so long as its employment shall not be more generalized.

Physiological Effects of Atmospheric Electricity.

We have already* spoken of the mortal effects that are produced by lightning upon man and animals, and of the remarkable peculiarities that accompany them. These effects are not the only ones. M. Boudin, who has made a particular study of the effects of lightning upon man, distinguishes in it three kinds of phenomena: 1st. cure of pre-existing affections; 2nd. the production of wounds and infirmities; 3rd. death. Among the affections the cure of which is produced by lightning, we find examples of rheumatismal afflictions, paralysis of the limbs, amaurosis, and deafness. †

* Vol. III. p. 148.

† M. Guérard relates, on the authority of Tulpius, that a young man who had been dumb for three years, after the removal of half of his tongue, felt a great movement in the muscle of this organ at the moment when he saw a flash of lightning shine forth, followed by a violent clap of thunder, and he immediately recovered his speech. (*Dictionnaire de Médecine, ou Répertoire des Sciences Médicales*, Paris, 1835, vol. ix.; article *Electricity*, p. 218.)

All these cases, which are very rare, would seem to prove that a powerful artificial electric discharge, such as that of a battery of Leyden jars, might be capable of producing the cure of certain affections; but the chances of danger are so much more great than those of cure, that we should not dare to advise having recourse to such a method as this. Indeed, among the morbid affections that are produced by lightning, it is very remarkable that, independently of many others, we find all those that are cured by electricity, such as transitory or persistent paralysis of the limbs, amaurosis, deafness, &c., with or without perforation of the tympanum; then, besides more or less extensive burnings, various eruptions, partial or total depilation of the body, nasal, buccal, auricular hemorrhage, cataract, dumbness, imbecility, abortion. We shall not dwell upon the description of these various accidents, which have been more than once established, and which have been treated by the ordinary therapeutic processes; we shall not confine ourselves to insisting upon the cases of death, and upon the curious circumstances which they frequently present.

It sometimes happens that death is only apparent; M. Boudin quotes the case of a man struck by lightning, who manifested no appearance of life until after an hour and a quarter, notwithstanding all the assistance that had been bestowed upon him. Notwithstanding, he at last recovered his consciousness, and, with this, all the strength of his intellect; but his sight was totally destroyed; all the various parts of his body no longer seemed to belong to him, so obtuse were his sensations, and so difficult were his movements. At the end of three weeks the numerous burns were still very acute, the pulse low, frequent, and irregular; sleep was unsettled; during the day almost continual drowsiness, heavy and fatiguing frontal headache, occasionally extending as far as the occiput. A remarkable thing is that the senses of smell, taste, and especially of hearing, had acquired greater delicacy. The prostration was complete; there was a veritable resolution of the muscular forces; the whole of the body, in the displacements that it was made

to undergo, was, as it were, a dead mass, obeying at pleasure gravity; painful cramps were very frequently manifested in it, especially during the night. Thanks to an energetic treatment of baths, sulphate of quinine administered every day, frequent application of leeches behind the ears, even the employment of electricity near to a wound, which had produced an immediate relief, the patient at last became gradually restored; it was only at the end of three months that his state of feeling, which had been very much impaired, became very nearly normal; that the state of transpiration, which had hitherto been completely null, reappeared; and that he recovered the consciousness of a substantial union between his different limbs. Vision, which had been re-established, but very imperfectly for one eye alone, at the end of a week after the accident, at last returned for the other eye also. Finally, at the end of four months, the cure being well advanced, the treatment ceased; and the re-establishment at last became complete.

Returning to the cases of death, nothing is more variable than the circumstances which accompany them. Sometimes the individual struck by lightning is killed dead on the spot; the dead person remaining in the position in which he was,— seated, standing up, or on horseback; sometimes he is hurled to a considerable distance. Sometimes lightning completely strips the victims and carries away the body; sometimes, on the contrary, it burns and disorganizes the body, and leaves the clothes untouched. Sometimes the body of the person struck with lightning seems to brave the laws of decomposition; sometimes, on the other hand, the most rapid and most horrible putrefaction immediately seizes upon the corpse; mutilations in man, with separations of the parts of the body, rarely accompany death occasioned by lightning; according to several hundred observations of individuals, struck by lightning, M. Boudin states that he has only met with six cases of mutilation properly so called; but in these six cases are found four partial or total tearings out of the tongue. The prominence of the eyes is cited by several authors as a phenomenon which

is frequently observed upon individuals struck with lightning. We also sometimes notice upon them a small hole in the skull, and even, but more rarely, the complete fracture of the bony part of the head. With regard to disorder in the internal organs, such as the lungs, the heart, the intestines, &c., they are frequently observed, either insulated or concurrently with the other affections. In a word, nothing is more variable than the condition of the body after death, among individuals struck with lightning. This is, in great part, very probably due to the route which electricity follows in its passage through the body,—a route which itself depends upon the direction according to which the electricity arrives; on the attitude of the individual, and on the relative position of his limbs, at the very moment when the lightning strikes him; on the greater or less degree of electric conductibility of the different parts of his body* and of his garments; and, finally, also on the external circumstances in the midst of which he is situated, such as his insulation and his approximation to conducting or insulating objects. But all these elements, which concur in the production of the special effects that accompany the general phenomenon, are almost always very difficult to determine, and cannot, consequently, be easily studied with a view of being explained.

An interesting question, and one that has not yet been solved, is to know how lightning kills, when, at least, the corpse presents no organic lesion to which the death of the individual that is struck may be indirectly attributed. M. Brown-Séquard, who was much occupied with this subject, sets out from the principle that every cause of excitement of the nervous or muscular forces acts in such a manner as to diminish the quantity of these forces, which, in a given moment, are found in the individual, more in proportion as this excitement is more energetic; all known facts

* There exist certain individuals who enjoy a kind of immunity against lightning, which is probably due to the defect of electric conductibility of their bodies. The same fact has been very frequently observed in the persons placed in the circuit that is formed in order to pass the discharge of a Leyden jar, and who do not transmit it.

demonstrate the accuracy of this law. It follows from this that lightning, inasmuch as it is an extremely powerful cause of excitement, will bring about the expenditure of the whole quantity of the nervous and muscular forces on individuals that may be struck by it; these forces being annihilated, we can perfectly well understand that life must immediately cease; because none of the vital acts of any importance could be accomplished in the absence of these forces. Thus, then, lightning kills by exhausting the whole quantity of the dynamic forces that are possessed by the animal economy, which explains the death that takes place in the absence of all visible lesion of the organs. This explanation, which is especially applicable to the cases of death produced by the return-shock*, appears to us to be about to be completed by a somewhat more precise examination of the manner in which lightning is able to exhaust, as M. Brown-Séquard says, the dynamic forces of the animal economy. It is evident, that the powerful electric discharge, under the influence of which the living body is circumstanced, imparts at once to the molecules of all the nerves, as to those of all the muscles, a different arrangement from that which they possess under the action of the vital force, and analogous to that which is brought about by the passage of an artificial discharge or current in one part only of the muscles and the nerves. The generality, joined to the intensity, of the electric action, in the case in which it is brought about by lightning, should produce at once a momentary but general suspension of the exercise of the vital force, and a molecular disorganization of the muscles and the nerves which prevents this force from resuming its empire†, and, consequently, makes it definitively disappear; since it no longer possesses the means of manifesting itself. The putrefaction that so rapidly arrives in the case with which we are now occupied, with

* Vol. III. p. 151.

† The effect of lightning in the case with which we are occupied would be very difficult of comprehension, were it not by means of the electricity which is possessed by the molecules, which are naturally bipolar, of the living organism, which makes communication between the nervous centres and the different parts of the body; whilst, the principle being admitted, we can conceive that the disturbance which may be introduced into the regular exercise of this communication from external electricity, is as powerful as that of lightning.

individuals struck by lightning, is a very powerful proof in favour of the explanation that we have just been giving; or that which, in general, retards decomposition, after death, is the conflict that still for some time exists between the arrangement that the organic molecules had assumed, under the influence of the vital force, and the arrangement which they must assume when, like the molecules of inorganic matter, they obey nothing beyond the ordinary physical forces, and in particular the electric forces, with which they are naturally endowed. Now, this conflict can no longer exist after death in the individuals on whom the action of lightning has been direct, and has consequently destroyed for ever, in all parts of their body, the arrangement brought about by the influence of the vital force, in order to cause that one to predominate which arises only from the exercise of the electric forces, which necessarily brings on, and that in an immediate manner, the formation of new compounds, and, consequently, decomposition. It is no longer the same with individuals upon whom the mortal action of lightning has been only indirect, and who have succumbed, either to the lesion of an essential organ or to an asphyxia, as may take place by the contraction of the respiratory muscles, when the electric discharge is directed principally upon these organs. In these cases, in fact, putrefaction arrives much less rapidly, and is preceded by cadaveric rigidity, which probably does not show itself, except for an instant, in the preceding case. Nothing better than the facts, of which we have been speaking, seems to prove the accuracy of the theory that we have given upon the physical and immediate cause of the animal decomposition that follows death,—a decomposition which is nothing else than the consequence of the exercise of the physical and particularly of the electrical forces, when the particles, that are endowed with them, are no longer under the influence of the vital force.*

* A very recent work of M. Brown-Séquard's (*Comptes Rendus de l'Académie des Sciences*, of October 5th, 1857) comes quite in support of our manner of viewing it, by showing that repeated muscular contractions bring about the complete death of a limb more promptly, that is to say, the disappearance of muscular irritation, the appearance and disappearance of cadaveric rigidity, and, finally, the

Atmospheric electricity does not act upon man by lightning only; it is simply sufficient that the weather be stormy, and the atmosphere charged with electricity, for an effect upon the organism to result from it. Healthy and hearty individuals feel an inconvenience, an agitation, a heaviness, difficult to express; their muscular system is more sluggish; individuals afflicted with rheumatism feel their pains renewed; neuralgias increase in intensity, or their paroxysms reappear. In general, patients afflicted with a chronic or acute affection, at the moment of a storm, feel an aggravation of the principal accidents; they are more fatigued, more agitated, and their febrile state increases. It is very probable that these different effects are due to the escape of electricity, that takes place through the body during stormy weather,—an escape taking place through the whole body, through the nerves as well as through the muscles, disturbs the equilibrium that exists in the normal state; and consequently must rouse into activity, or must act in opposition to, certain functions dependent upon nervous influence.

An indirect effect of atmospheric electricity upon the organism is the production of ozone, in greater or less proportion, in the atmosphere, and the influence that results from it upon the animal economy. The effect of ozone has been compared with that of chlorine; consequently it is upon the respiratory organs that oxygen in the ozonized state would act; whence it has been concluded that the presence of ozone in the atmosphere might be connected with certain epidemic catarrhal affections, such as *influenza*. On the other hand, it would appear from the researches of certain physicians, both in Europe as well as in the United States, that ozone would have the property of exercising a deleterious action upon miasmata, and that its presence in the air would on this account exercise a happy influence

development of putrefaction. And, in fact, everything that gives to the particles of the muscles a forced position, different from that which they assume naturally under the action of vital force, tends to destroy muscular irritability, which is altogether independent of nervous action, and which is inherent in the vitality of the muscles, and consequently facilitates decomposition, or, which comes to the same thing, putrefaction.

over certain epidemics. M. Gaillard, a physician at Charlestown, in the United States, and M. Wolf, at Berne, in Switzerland, have both studied this question under different points of view, and have equally proved the very decided influence of ozone, the presence of which in the air can only be due to atmospheric electricity, and not, as has been wrongly supposed, to vegetation.

Dr. Boeckel, of Strasbourg, has made regular ozonometric observations in that city, by employing, as did M. Wolf, Schoenbein's ozonometer, that is to say, bands of paper covered with a solution of iodide of potassium in starch. These bands are exposed for a sufficiently long time (twelve hours) to the atmospheric air; they are then plunged into pure water, in order to compare them with a scale passing from white, which is the 0° of the division, to dark violet, which is the 10°. The following is a curious table of observations, made comparatively at Berne by M. Wolf, and at Strasbourg by M. Boeckel. In general, the ozonometric reaction is more feeble at Strasbourg than at Berne; and by the side of the observed reaction, there is found for Strasbourg the reaction, calculated by the comparison of the means of the year of Strasbourg with those of Berne; the observations were made in 1854.

	Berne.	Strasbourg.	
		Observed.	*Calculated.*
From June 21 to July 16	9·92	7·88	7·54.
July 17 to Aug. 12	5·31	2·48	4 04.
Aug. 13 to Sept. 4	5·74	2·30	4·36.
Sept. 5 to Sept. 30	5·00	5·12	3·80.
Oct. 1 to Oct. 25	7·20	6·52	5·47.

We may remark that, during the second and third periods, the reaction of ozone presented at Strasbourg an exceptional weakness, which justifies the hypothesis of Dr. Boeckel, of the connection that exists between the presence of cholera and the diminution of the quantity of ozone in the atmosphere; for these two periods are those during which cholera was most severe at Strasbourg. In the fourth period cholera had ceased at Strasbourg, and was severe at Arau; the reaction also was found slightly more feeble at Berne, which

is very near to Arau, than at Strasbourg; then, in the fifth period, in which the disposition to cholera disappeared at Berne as well as Strasbourg, the ozonometric reaction recovered its superiority at Berne. We have been able also to prove that the minimum took place at Berne, for the reactions of ozone, at the same time the cholera had its maximum of intensity at Arau, that is to say, from the 12th to the 16th of September.

We shall not dwell upon the relations that we have just been pointing out, seeing that there would be need of a great number of observations, in order to receive a positive confirmation. We shall confine ourselves to remarking, that the influence, evident in every case, of ozone upon the organism, is attributed, according to some, to an indirect action of this chemical agent, which would destroy miasmata, as does chlorine; and, according to others, to a direct action, which would bring about certain sickly tendencies, either by increasing or diminishing in intensity. Whatever it may be, the subject is interesting, and shows under how many divers forms, some indirect, others direct, atmospheric electricity may act upon animal life.

Does it likewise act upon vegetable life? Since the time of the Abbé Bertholon, who, in 1783, devoted an entire work to the action upon vegetables of electricity, as well atmospheric as artificial, to the trials made ten or twelve years ago in England, under the name of Electro-culture, by Mr. Forster and Mr. Solly, in order to expedite vegetation by drawing down atmospheric electricity, with a view of leading it into the ground by means of metallic rods, the question has remained undecided. It has been assumed that storm-showers had a fertilizing virtue, which ordinary rains did not possess; it has been supposed to have been found that germination, and even vegetation, were accelerated in the vicinity of lightning conductors planted in the ground. But, on the other hand, comparative experiments made upon plots of land placed under conditions as much as possible exactly similar, some exposed to the action of atmospheric electricity, others withdrawn from this action, have not given very deci-

sive results; which is due to the fact that, supposing that electricity has an influence, there are so many other causes which also have one, such as temperature, solar light, independently of the nature of the soil, which is rarely identical in two different places, that it is very difficult to discern the part that may be assigned to atmospheric electricity. However, without exaggerating this part, might it not happen, notwithstanding, that vegetables were one of the channels by which is brought about the regular and constant centralization of the negative electricity with which the terrestrial globe is constantly charged, with the positive that the vapours of the sea carry off into the atmosphere? Now, this centralization, which might take place through the moist parts of plants, would exercise upon them a chemical action, by bringing the oxygen and the principal acids into the part of the vegetable that is in contact with the air, which would serve as an electrode*; and the hydrogen, as well as the alkaline principles, into the lower part of the roots, or rather into the ground which touches them. But we here touch upon the most delicate questions of vegetable physiology; notwithstanding the interest which they present, we could not discuss them without exceeding the limits that we have imposed upon ourselves; we must confine ourselves to pointing them out as being a worthy subject of interesting research.

List of the principal works relative to subjects treated on in this Chapter.†

Galvani, Volta, Humboldt, Nobili, Matteucci, Marianini, Dubois-Reymond.—*Vide* the indication of their works on Physiological Electricity, vol. ii. p. 517., and vol. iii. p. 89.

Marianini.—Case of Paralysis. *Ann. de Chim. et de Phys.* t. liv. p. 366.

Nobili.—Case of Tetanus. *Idem.* t. xliv. p. 60.

Matteucci.—*Idem. Bibl. Univ.* t. xv. (1838) p. 188. Phenomena of Muscular Contraction. *Ann. de Chim. et de Phys.* (*New Series*) t. xlvii. p. 129.

* Faraday has shown, by several experiments, that the air is able to serve as an electrode in electro-chemical decompositions, produced by discharges of ordinary electricity. (Vol. II. p. 445—447.)

† The number of memoirs in which the application of electricity to physiology, and in particular to therapeutics, is treated of, are so considerable, that we confine ourselves to pointing out the most important and the most recent, referring for others to the special treatises upon the matter, of which we likewise give the name.

Helmholtz. — Velocity of the Propagation of Nervous Action. *Ann. de Chim. et de Phys.* (*New Series*) t. xliii. p. 367.

A. J. Duval. — Historical Glance on the Application of Electricity to Medicine. *Arch. des Sc. Phys.* (*Bibl. Univ.*) t. xlii. p. 8.

Masson. — Physiological Effects of Induced Currents. *Ann. de Chim. et de Phys.* t. lxvi. p. 26.

Dr. Duchenne de Boulogne. — On Localised Electrization, and its Application to Physiology, to Pathology, and to Therapeutics. Paris, 1855. One thick vol. in 8vo. Several Memoirs in the *Archives de Médecine*, and the *Bulletin Général de Thérapeutique.*

Dr. A. Becquerel. — Application of Electricity to Therapeutics. One vol. in 8vo. 1857.

Dr. Bouvier. — Relation on Medical Electricity to the Academy of Medicine. (*Bulletin de l'Académie de Médecine*, Paris, 1856, l. xxi. p. 650. *et seq.*)

Remack. — Physiological and Therapeutic Action of Currents. *Comptes Rendus de l'Académie des Sciences*, t. xliii. p. 603. and 655.

Jacubowitsch. — Histology of the Nervous System. *Comptes Rendus de l'Académie des Sciences*, t. xlv. p. 29.

Prevost and *Dumas.* — Treatment of Calculi by the Battery. *Ann. de Chim. et de Phys.* t. xxiii. p. 202. and 334.

Bonnet. — *Idem.* *Bibl. Univ.* t. lviii. (1835) p. 391.

Bence and *Jones.* — *Idem.* *Phil. Trans.* 1853.

Poey and *Vergnès.* — Extraction, by the Battery, of Metals in the Organism. *Arch. des Sc. Phys.* (*Bibl. Univ.*) t. xxviii. p. 208.

Petrequin. — Cure of Aneurisms by Electro-puncture. *Arch. de l'Electr.* t. v. p. 485.

Middeldorpff. — Galvano-caustic. *Comptes Rendus de l'Académie des Sciences*, t. xliii. p. 678.

Philippeaux. — *Idem.* *Practical Treatise on Cauterization*, vol. i. in 8vo., at J. B. Baillière's, 1856.

Jules Regnauld. — *Idem.* *Idem.*

Boudin. — Physical and Medical Electricity of Lightning, and of its Effects upon Man. *Annales d'Hygiène Publique*, 1854, 1855, t. ii. p. 395.; t. iii. p. 241.; t. iv. p. 241. *Treatise on Medical Geography, Medical Statistics, and Endemic Diseases*, Paris, 1857, two vols. in 8vo., t. i. p. 455.

Wolff. — Physiological Influence of Ozone. Pamphlet in 8vo. Berne, 1855.

Gaillard. — *Idem.* Charlestown, 1856. Pamphlet in 8vo.

Bertholon. — Electricity of Vegetables. 1783. One vol. in 8vo.

Walker. — Electro-culture. *Arch. de l'Elect.* t. v. p. 535.

Fyfe and *Peersall.* — *Idem.* *Arch. des Sc. Phys.* (*Bibl. Univ.*) t. ii. p. 292. and 293.

APPENDIX.*

1. — *Recent Researches upon Electro-static Induction.*

A FEW days before his death, M. Melloni, in a letter addressed to M. Regnault, and inserted in the Comptes Rendus de l'Académie des Sciences (t. xxxix. p. 177.), made known a new theory of electro-static induction, founded upon the principle, that the electricity, induced in the nearest part of the inducing body, and of the contrary name consequently to that of the electricity of this body, is completely *disguised*, that is to say, without mobility and without tension, except so far as to the inducing electricity, whilst the free electricity is endowed with these properties. He thus generalized the principle that had been more or less admitted into the theory of the condenser, and he explained the divergence of the two pendulums placed at each of the extremities of an insulated metal cylinder, brought near to an electrized body, by attributing the divergence of that one of the pendulums which is nearest to the electrized body, to the attraction exercised by the electricity of this body, and not to the action of the induced electricity, which, according to him, being all disguised, could not produce such an effect. M. Riess has happily modified this experiment, in order to

* We have summed up, under the title of *Appendix*, at the end of the Third and last Volume of this Treatise, some additions to the matters discussed in the three volumes, the object of which is to complete the subjects in which, either by omission, or in consequence of a publication subsequent to our own, we had left some blanks. We do not pretend to have collected together all; but we hope, at least, to have pointed out the most important features among those to which recent works have directed the attention of philosophers.

show that Melloni's explanation could not be admitted. He places above and very near to a sphere electrized positively, an insulated conductor, cylindrical and vertical, carrying towards its extremities small balls of elder-pith. The two pendulums diverge, the one below more powerfully than the one above, without our being able to attribute its divergence to the action of the electricity of the sphere; for, this action can evidently be only a vertical force, whilst that which causes the pendulum to diverge is horizontal; besides, it is easy to prove that the two pendulums have a contrary electricity. We are likewise able to prove, by touching the induced rod with an insulated conducting body of small dimensions, that that electricity, which is said to be disguised, has not lost the property of passing from one conductor to another.

If there is no electricity disguised in the experiment, by which we demonstrate the decomposition of the natural electricity of an insulated conducting body by the influence, at a distance, of an electrized body; neither should there be any in apparatus, such as the condenser and the Leyden jar, by means of which the condensation of electricity is obtained. However, by an incredible contradiction, the greater part of the Treatises on Physics, which do not admit disguised electricity in the former case, admit it in the latter; and yet there are no other differences between the two cases than those, which are due to the form and distance of the two bodies, of which the one is electrized and the other induced. M. Riess has clearly felt that this contradiction could not exist; thus he has given a new theory of the condenser, which, no longer resting upon the hypothesis of disguised electricity, no longer constitutes an exceptional case to the general laws of the distribution of electricity, and to the principles established by Æpinus, Coulomb, and Poisson, upon the equilibrium of electricity on the surface of conducting bodies.* But the problem then becomes difficult, and no longer allows of a simple and general solution, as in the hypothesis of disguised electricity; it is by

* Annales de Ch. et de Phys. (N. S.), t. xlii. pp. 374. 376.

checking, by means of experiment, the accuracy of the formula founded upon this hypothesis that M. Riess succeeded in demonstrating its want of foundation. A series of experiments, made with condensers, the plates of which were at different distances, and possessed surfaces of greater or less extent, and in which the plate that does not receive the electricity communicated more or less perfectly with the ground, have demonstrated that the problem of the condenser is a complex problem, depending upon all the peculiarities that may be presented by the arrangement of the apparatus, in a word, of the same kind as all problems relative to the distribution of electricity. We see there is no condensing force depending simply upon the distance of the plates, or simultaneously on their distance and on their superficies. There is, therefore, no necessity to seek for a simple expression of this force, and for the verification of the formula $\frac{1}{1-m^2}$* becomes superfluous. Nevertheless, M. Riess has been engaged in seeking for an accurate and convenient means of determining the quantity m, that is to say, the relation of the two absolute quantities of electricity which accumulate upon the plate of the condenser. He has renounced the process, which consists of separating the two plates and of measuring the electric densities in points similarly situated on these two plates, on account of the difficulties that arise from the necessity of making the comparison of the two electricities of a different nature very rapidly. He has so arranged the experiment as to have only to compare electricities of the same kind. For this purpose he took the density of the electricity in a point of the collecting plate before bringing it near to the condensing plate; then he took it again, after having brought the two plates nearer to each other, suppressed the communication of the condensing plate with the ground, and connected the two plates by an insulated metallic arc, so that they possessed nothing beyond the excess of the electricity of the former over that of the latter; he then began the experiment again, still maintaining

* *Vide* Vol. I. p. 530.

the condensing plate insulated and without communication with the ground, so that there were on this plate equal quantities of the two contrary electricities. These last experiments have furnished him with the necessary data for calculating, by means of very simple formulæ, the value of the relation sought after.

The principle of disguised electricities, justly generalized, if it is true, by Melloni, has found skilful defenders, among whom, one of the most ardent and the most ingenious, is, undoubtedly, M. Volpicelli. The learned Italian philosopher concludes, from many experiments, which we cannot introduce here *, that induced electricity has no tension except relatively to inducing electricity; and that consequently, during induction, it can neither cause electrometers to diverge nor produce an induction upon free electricity of the contrary sign, nor neutralize itself with it; that consequently this free electricity must distribute itself upon the whole of the induced body, as if that which is disguised did not exist, obeying the ordinary laws of distribution, joined to the repulsive influence exercised by the inducing electricity, which is of the same nature. Among M. Volpicelli's experiments we will quote the two following, which appear to us the most simple and the most conclusive in favour of his thesis, especially the second. The first consists in arranging, towards the extremity of the insulated and induced metallic cylinder, the end of a very thin conducting wire, insulated and directed perpendicularly to the axis of the cylinder, the other end of which is connected with an electroscope. By means of a silk thread the first end of the wire may be easily placed in contact with the surface of the induced cylinder, from which it is only one-fiftieth of an inch distant. By means of a large cylinder of sealing-wax, electrized by friction, induction is produced upon the cylinder and upon the wire, by placing them both in communication with the ground; this communication is then interrupted so as to insulate them both; and the end of the wire is immediately placed in con-

* *Comptes Rendus de l'Académie des Sciences*, t. xli. p. 553.; t. xliii. p. 719.; and t. xliv. p. 917. *Archives des Sciences Physiques* (*Bibl. Univ.*), 1856 and 1857.

tact with the cylinder, by means of the silk thread; the electroscope gives no sign of electricity, whence M. Volpicelli concludes that induced electricity has no tension. The same experiment is repeated by placing the conducting wire, and not the cylinder, in communication with the ground during the induction; then, after having insulated it, its extremity is placed in contact with the cylinder; the electroscope instantly indicates free electricity, similar to that of the inducer; and this, whatever may be the point of the surface of the induced cylinder which touches the end of the conducting wire; only there is a less quantity of electricity in the end of the cylinder that is nearer to the conducting body than in that which is more distant from it. Objection may be made against this experiment, that the conducting wire, which is made to communicate with the induced cylinders, cannot be considered as a simple vehicle of electricity; but, that as soon as it is in contact with this cylinder, it constitutes with it a new system of conductors, in which the electricity, produced by the induction of the electrized wax, must assume a new distribution, to which is due the presence, at the extremity of the wire in contact with the electroscope, of the electricity of the same name as that of the inducer. M. Volpicelli's second experiment, which we also propose to quote, is free from this objection; it consists in touching the different points of the surface of the induced cylinder with a very small proof plane, so that it may be confounded with the element of the surface upon which it is applied; a disk of copper, one-fifth of an inch in diameter, and a hundredth of an inch in thickness, fixed with sealing-wax at the extremity of a very thin glass tube, fulfils this condition. After having verified that there is no sensible transport of electricity through the air, between the induced and the inducing bodies,—a verification always necessary,—the extremity of the induced cylinder that is nearest to the inducer is touched with the small proof plane, and electricity similar to that of the inducer is found; it is found in all the points of the surface of the induced cylinder, from one end to the other. Whence it is concluded that induced electricity of the contrary name to that of the in-

ducer has no tension; and that that of the same name which is free, is distributed over the whole surface of the induced cylinder, as if it possessed no other electricity. If the proof plane is of large dimensions, it is then charged with electricity of the contrary name to that of the inducer, which is due to the fact that it plays itself the part of an induced body, which still retains, after having been withdrawn from induction, a portion of the induced electricity — that of the same name as the inducing electricity being in part dissipated in the air.

Notwithstanding all which this latter experiment presents specially in favour of the thesis that is supported by M. Volpicelli, we confess that we have some difficulty in comprehending such a state of electricity as this, which is able to lose its ordinary properties, except in regard to the electricity of inducing bodies; and it is difficult for us to renounce the very simple and general laws of the equilibrium of electric forces, such as they have been established by Poisson. Thus, we think that, while still taking into serious consideration the very remarkable experiments of M. Volpicelli, it would still be necessary to vary them, by studying them more closely, with a view of inquiring whether they are really irreconcilable with the old theory. That of the proof plane in particular would deserve a similar examination. This is a research that we should permit ourselves to recommend to the attention of philosophers, and, above all, to that of M. Volpicelli himself, who has opened this new field of investigation.

In connection with electro-static induction, we cannot in silence pass over the remarkable discussion that has arisen between MM. Riess and Faraday, upon the part played by dielectrics in this induction.* Mr. Faraday, as we have said, not admitting action at a distance, considers that induction is brought about by the intervention of the insulating particles that separate the induced body from the inducing body, and in particular by the intervention of the particles of a plate of gum-lac, if it is a plate such as this that is inter-

* *Archives des Sciences Physiques* (*Bibl. Univ.*), t. xxxi. p. 48.

posed. There result from this, differences between the various insulating or dielectric bodies, with regard to their faculty of transmitting induction. According to M. Riess, every plate, intermediate between an inducing and an induced body, whether it be of a conducting substance or not, is immediately charged by induction with the two electricities, which are arranged in a certain manner upon the two faces of the plate. The distribution of the two electricities cannot be determined in a rigorous manner, in the case of the non-conducting plate, as it may be in the case of the conducting plate; but it does not follow that there is an essential difference between the action of a conducting body, and that of an insulating body, relatively to electro-static induction, although it is very evident that the manner in which induction is produced upon a conducting plate and upon a non-conducting plate is not the same in every respect. Each of the two learned philosophers invokes, in favour of his opinion, an experiment, in which a disk of gum-lac, placed under the influence of the positive conductor of an electric machine, and exposed upon that surface which is not turned on the side of the conductor, to the action of the flame of a spirit lamp, is found to be electrized negatively. But M. Riess justly remarks that this experiment is very incomplete, the part played by the spirit flame being less simple than Mr. Faraday supposes; and he succeeds in explaining the negative state of the surface exposed to the flame, which, according to the theory of induction, ought to be positive, without being obliged to renounce this theory, and to admit Mr. Faraday's ideas. We have already remarked*, that the principle of action at a distance may be reconciled with the effects obtained by Mr. Faraday upon the influence of dielectrics, by admitting that these latter are polarized, when they are placed between two bodies charged with contrary electricities.

2.—*Influence of Mechanical Actions upon Magnetization.*

We have already spoken, in our First Volume, of the influence of mechanical actions upon magnetism. Since then

* Vol. I. p. 144.

some very interesting researches of M. Wertheim's have appeared upon this subject, of which we are about to give an abridged summary. It had been long known that mechanical actions modify the magnetic state of a bar of iron, placed under the influence of the earth, or of any magnet whatever. In order to explain these facts, we confined ourselves to saying, that every mechanical action diminishes, momentarily, the coercive force of a magnet, and thus permits the molecules of which it is composed, either to obey more completely external magnetizing forces, or to return to a state nearer to the ordinary state of equilibrium, when the cause of magnetization has ceased. This, in fact, is what takes place in a general manner; but among mechanical actions there is one, torsion, the effects of which upon the magnetism of magnets are subject to particular laws. M. Wertheim, in a Memoir upon the magnetic effects of torsion, has made known facts which establish, as we shall see, new relations between this mechanical action and the magnetism of the magnets upon which it is exercised.

M. Wertheim's apparatus is a horizontal table, upon which two jaws, into which are fitted the extremities of the bars, are able to move along a rail, so as to leave between them any desired distance. One of the jaws is fixed, and the other is centred upon the axis of a large pulley, at the circumference of which two equivalent weights, acting at the extremity of a same diameter, one directly from above downwards, the other from below upwards, by means of a return-pulley, constitute the torsion pair: into the anterior surface of the wheel is fitted a circle, divided into sixths of sexagesimal degrees, and the torsion angles are measured to the sixth of a minute nearly, by means of a fixed vernier. With this apparatus we are able to twist the bar *dextrorsum* or *sinistrorsum*, to measure in each case the angles of the temporary or permanent torsions, to allow it to return by untwisting to its original position, or finally to maintain it under a fixed temporary torsion, which must not be confounded with a permanent torsion.

The part of the apparatus which serves to magnetize the

bar, and to study the variations of its magnetism, is composed of two helices, in the axis of which it is placed. One, the inducing, is formed of a large wire, and receives the current of the battery; the other, of a thinner wire, includes in its circuit a sensitive galvanometer. All the sudden variations which the magnetism of the bar undergoes give rise to induction currents, the direction and intensity of which are measured by the galvanometer. The position of the induced helix, in respect to the bar, is a matter of indifference; but it is of great importance that a magnetized bar should not present any consequent points: it would then comport itself, in respect to the galvanometers, like two magnets turned in contrary directions, and developing consequently currents of contrary directions.

We know that soft iron and steel are two extreme terms which do not in reality exist, that is to say, that there is no soft iron which does not retain a little magnetism, nor is there any steel which does not lose some, when the cause of magnetism has ceased. M. Wertheim should have endeavoured to distinguish, in the effects of torsion, the part which is referable to temporary magnetization from that which is referable to permanent magnetization; and, for this purpose, to measure directly the permanent magnetism of the bars by the number of the oscillations of a magnetized needle.

In a first series of experiments upon bars, differing by the degree of hardness of the iron, M. Wertheim has established the following facts. The mechanical action of torsion or detorsion does not, of itself alone, develope magnetism; but, when a bar is placed under any magnetic action whatever, the torsions render the soft iron capable of fixing, in a permanent manner, a much more considerable quantity of magnetism than if its mechanical equilibrium had not been deranged. The following then is the important fact: as soon as iron has acquired all the temporary or permanent magnetism that it is capable of acquiring under the action of a given magnet, every torsion that is exercised upon it causes its total magnetization to diminish, whilst the corresponding de

torsion re-establishes it.* Finally, if we withdraw the bar from external magnetic action, the torsions or detorsions, acting like all other mechanical concussions, destroy promptly the temporary magnetization, but continue indefinitely to exert their effect upon the permanent magnetization which is diminished by the torsions and re-established by the detorsions. M. Wertheim's experiments, repeated upon bars of different kinds, have shown to him that the harder the iron is the more torsions are necessary in order to make it take or lose its temporary magnetization; and with regard to steel, the torsions greatly accelerate the establishment of magnetic equilibrium; but when once established, it can no longer be deranged by torsion alone, without the aid of a magnetic influence.

In this first series of experiments the bar was not subjected to any torsion (*mechanical zero*) at the moment when the magnetizing circuit was closed or opened; and it was starting from this position that torsions had been applied, always sufficiently feeble for being capable of being considered as temporary. It was seen that the result of these experiments had been the coincidence of the *maximum* of *magnetization*† with the position of the mechanical zero. M. Wertheim has successively modified his mode of experimenting in the following manner.

1st.—He commences by giving to the bar any temporary torsion; he afterwards magnetizes it; by then repeating the preceding experiments, the same phenomena are again found, that is to say, everything takes place as if no temporary torsion had been exerted until after the magnetization of the bar. Thus, in this case, a fresh coincidence of the maximum of magnetization with the mechanical zero.

2nd.—Any permanent torsion is imparted to the bar before magnetizing it; and it is found that this bar, thus modified mechanically, is not so under the magnetic relation, and that

* In fact, each torsion, in one direction or another, developes in the induced helix a current, called by M. Wertheim *negative*, that is to say, resulting from a demagnetization, and the corresponding detorsion gives an equal current of the contrary sign.

† That is to say, of the position of the bar, which is such that, on twisting it either to the right or to the left, its magnetism diminishes, and becomes what it was by the fact of detorsions.

the maximum of magnetization coincides with this new mechanical zero.

3rd.—Whilst the iron is under the action of the magnetizing current, a permanent torsion is applied to the bar; he then observes the displacement of the maximum, or a *rotation of maximum*, in the direction of the permanent torsion: the size of the angle varies according to the quality of the iron.

4th.—Whilst the bar is under the action of a temporary torsion the magnetizing current is interrupted; and this interruption produces a rotation of the maximum in the direction of the temporary torsion: the angle of rotation never passes beyond the angle of this torsion, but it is nearer to it in proportion as the iron is softer.

Setting out from these facts, M. Wertheim first took in hand to show that the hypothesis of the coercitive force is not sufficient to explain them. The explanation that has been given of them by M. Matteucci, by attributing the magnetic effects of torsion to the changes of volume which it produces in the bars, cannot, in the majority of cases, account for them in a satisfactory manner. M. Wertheim has then endeavoured to include these facts under a theory, according to which the magnetism would be due to vibrations, and in which the coincidence of their phases, destroyed by torsion and re-established by the corresponding detorsion, would produce the various effects of which we have spoken.

We are disposed to believe that these effects may be easily explained in the theory that we have admitted, and which consists in setting out from the principle that the molecules of iron being naturally surrounded by electric currents, magnetization is only the result of an exterior action, whether electro-dynamic or magnetic, which compels these currents to arrange themselves in a regular manner. Mechanical actions, and particularly torsion and detorsion, are able to facilitate or to oppose the magnetizing action, in the same manner as the greater or less amount of friction which a movable current suffers in its mode of suspension, more or less prevents this conductor from obeying the action of a current or of a fixed magnet. The variation of electric conductibility,

which is determined by magnetization in steel and in iron, according to Prof. Thompson, as we shall see further on, is a fresh proof to be added to those which we have already given upon the molecular change which accompanies magnetization, —a change which would consist in bringing the particles nearer together in the direction perpendicular to the line which joins the magnetic poles, and in separating them from each other in the direction of this line.

3.—*Influence of Temperature upon Magnetism.*

We have pointed out in a general manner, in the Third Part of this Treatise*, that elevation of temperature diminished, and in the end, when it was very considerable, caused the magnetism of magnetized bars to disappear. Since the publication of our First Volume, two distinguished philosophers, M. Dufour† and M. Wiedemann‡, have been occupied with this subject. (It is the summary of their researches that we give here.)

In order to study, in an accurate manner, the mode in which the magnetism of magnets at an elevated temperature comports itself, M. Dufour placed a magnetized bar in a copper case filled with oil, and heated by two spirit lamps; the magnetic intensity of the bar was measured by a magnetized needle, suspended freely above it and placed by various means beyond the calorific influence of the apparatus. He was thus enabled to prove that, at a temperature very far removed from red, magnets do not retain more than a very small fraction of their primitive force; when heated to redness, they no longer possess polarity, but this latter reappears by cooling. It was not until after having been heated four times to intense red that a bar finished by completely losing its magnetism. The influence of tempering has been proved in a very neat manner; bars of steel highly tempered lose a lesser proportion of their magnetism when they are

* Vol. I. p. 175.

† *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxi. p. 105; and t. xxxiv. p. 5. and 295.

‡ *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxv. p. 39.

raised from 50° Fahr. to 482°, than those which have undergone a more feeble tempering, and they also recover a less proportion of it when they are cooled. In general, when a bar is several times heated, the variation of magnetic intensity, corresponding to a same variation of temperature, diminishes more rapidly in proportion as the temper of the bar is less; and by repeated and successive heatings, a bar highly tempered is thus more promptly weakened than another at a lower temper. To sum up, it follows from this first series of researches, that the law of the variations of magnetic intensity with temperature must follow modifications for each heating of a same bar: besides, for one and the same experiment, it appears very complex, the variation of the intensity of the magnetism being greater between 212° and 392°, than between 32° and 212°, or above 392°.

In the formula of correction, relative to the influence of temperature upon the magnetism of magnetized needles, it is implicitly admitted, that if the elevation of temperature produces a diminution of magnetic intensity, its fall must produce an increase. Now, according to the experiments of M. Dufour, account must be taken of the absolute temperature at which the bar has been magnetized; and a change of temperature in one direction as well as in the other, setting out from this limit, produces a diminution of magnetism, as well by cooling as by heating; a diminution which disappears, more or less, by the return to the primitive temperature of magnetization. A very great number of experiments seem to confirm this important fact, which may be connected with the relation established by M. Wertheim between the state of mechanical equilibrium of a bar that is magnetized and its maximum of magnetization.

M. Wiedemann, in repeating M. Dufour's experiments, has verified that a fall of temperature below that at which the magnetization took place produces, in fact, a diminution of magnetism; but he has found that, if we continue to cause the bar to undergo successive variations of temperature, it soon enters into the general law, as M. Dufour has himself subsequently recognized, and that the degree of temperature

at which the bar has been magnetized no longer influences the direction of the variation of the magnetic intensity. That which, on the other hand, remains true, in an absolute manner, is the fact established by M. Dufour, that the variations of the magnetism of a magnetized bar at a temperature higher than those at which it has been magnetized, are more feeble than they would be if the magnetization had taken place at a lower temperature. More than this: the thermometric oscillations make a bar very promptly acquire an almost incomplete insensibility to feeble variations of temperature. Upon this point M. Wiedemann does not go quite so far as does M. Dufour, although he has also found that bars magnetized at 212°, heated and cooled several times, preserved, in respect to the influence of temperature upon their magnetism, only a sensibility much less than bars magnetised at 32°, exposed to the same variations of temperature. This last fact is of very great importance in the choice of needles which are to be employed for the observations of terrestrial magnetism, in which we seek for the condition most suitable for diminishing the corrections and errors due to temperature. The following are the rules which M. Dufour recommends to be followed in this respect: —

1st. To magnetize at a temperature *higher* than those in which the observations are to be made;

2nd. To cause the temperature of the needle to vary a great number of times (from 68° to 86°) between the temperature of magnetization and the minimum temperature to which it may be exposed;

3rd. To seek for the correction proper to the needle, *only after* making it undergo the operations indicated; a correction which besides will be determined, as shall be judged suitable, either by seeking for the true coefficient of variation for 1° of temperature, or by determining one or more empirical constants, according to the class of observations that we desire to undertake.

4.—*M. Felici's Theory of Electro-dynamic Induction.**

In the Chapter that we have devoted to electro-dynamic induction, we have said a few words upon the theories proposed by several philosophers, for the explanation of the facts that are connected with it; and, in particular, of those of Weber and Neumann. These theories, perhaps, possess the inconvenience of resting less upon the facts of induction itself, than, in truth, on its evident relations with electro-dynamic actions; they are, up to a certain point, the mathematical expression of Lenz's law; besides, they embrace only the phenomena of induction, produced by motion, without connecting them with those of induction by the opening and closing of the circuits. M. Felici has made electro-dynamic induction the subject of his numerous and interesting researches; he applied himself to collecting together the greatest possible number of facts, that might give birth to a mathematical theory of induction, which is thus deduced from experiment alone. The method which he has followed, is that which Ampère has applied to the theory of electro-dynamic actions; and the sum of his researches, of which we can here give only a succinct summary, is destined, we think, to throw light upon this part of dynamic electricity, as yet so little known, and so little explained.

M. Felici commenced by studying the laws of induced currents, produced by the opening and closing of a neighbouring circuit. The apparatus that he employed is a cylinder of wood, around which is coiled an insulated copper wire, forming a complete circle, and the two ends of which, twisted together, communicate with a galvanometer. This is the *induced circuit.* On the right, and on the left, at equal distances, are arranged similar conductors, formed by the wire, which joins the poles of a battery. These are the *inducing circuits,* in which a rheotome is introduced. In general, M. Felici's method consists in causing the two inducers to act simultaneously, so that their effects being contrary, the absence of the induced current proves their

* *Ann. de Chim. et de Phys.*, t. xxxiv. p. 64.

equality. The fact that the conductors, setting out from the cylinders, are wound together, enables us to refer the effects studied to circles alone.

The intensity of the induced currents is independent of the nature of the circuits. For this purpose, we have merely to substitute a ring of zinc for one of the copper rings, &c., and to prove that the needle of the galvanometer is always at zero.

The intensity of the induced currents is proportional to that of the inducing currents. For one of the inducing rings is substituted a ring formed of n equal wires; the inducing action of this system is equal to that of the other single ring, — that is to say, that the inducing action of n currents, each equal to $\frac{K}{n}$, is equal to that of a current, equal to their sum K. In an analogous manner, we may verify that the intensity of the induced currents is independent of the section of the wires of which the circuits are composed.

M. Felici, by means of this same apparatus, has been able easily to extend to the case of induced currents the theorem of sinuous currents, both in respect to the inducing circuit, as well as to the induced circuit; and, by resting upon this generalization, to determine the general form of the algebraic formula, which expresses the electro-motive force induced in an element. One particular case of equilibrium has enabled the author to determine one of the constants that enters into it; the other remains undetermined, and its value can be obtained only by experimenting upon open circuits, — the only case besides, in which the part of the formula, in which it enters, does not disappear.

After having thus expressed, in a general manner, the electro-motive force of induced currents, by the opening and closing of the inducing currents, the author has proposed to connect with this theory the production of induced currents by motion, and he thinks he has established the following theorem: —

The induced current developed in a conductor by the

closing of a circuit in a position A, is equal to the sum of the induced currents that are developed in it, by bringing the closed circuit from a position, sufficiently removed from the position A; and, more generally the sum of the induced currents, produced by the movement of the current from B to A, is equal to the difference of the induced currents developed by the closing of the circuit successively in the two positions A and B.

The experiments upon which this theorem rests, show the proportionality of the quantities, the equality of which the author announces; and they appear to us to require to be studied in more general cases, and, perhaps, at the same time, more simple ones. Whatever the case may be, this theorem being admitted, gives the means of calculating the electromotive forces induced by any movement whatever; and these formulæ are in accordance with those of MM. Weber and Neumann.

M. Felici then entered upon the case of open induced circuits, which gives rise to the phenomena known under the name of *unipolar* or *axial* induction, already studied by Mr. Faraday, then by MM. Weber and Matteucci. We know that a cylindrical magnet, that is to say, one whose magnetism is supposed to be symmetrically distributed quite round its axis, is able to produce, on turning around this same axis, induced currents; but under the condition that the circuits in which they are developed shall have a portion in motion; in other words, we here find exactly the reciprocal of the laws of the rotation of a current by a magnet,—that is to say, that every time the magnet would produce an action upon the current, the movement of the circuit would produce a current. This kind of induction, which differs from ordinary induction, in that we see no relative change of position between the circuit and the magnet, is connected, in regard to its laws, with ordinary induction, by the following experiment, which M. Matteucci was the first to quote, and which has been taken up with greater rigour by M. Felici. We have a cylindrical electro-magnet and a metallic disc, arranged perpendicularly to the axis of the cylinder, with its

centre on this axis. Of the two wires of the galvanometer, one communicates with the disc; with regard to the other, the surface of which must be covered with silk, a spiral is formed of it, which is so arranged, that no induced current is developed in it, when the circuit, which magnetizes the electro-magnet, is closed. If, now, the bare end of this latter wire is made to describe rapidly any curve upon the disc, taking care that the wire of the spiral is exactly superposed upon the curve described by its extremity, the needle of the galvanometer remains at 0°. Now, the part of the wire which, setting out from a position in which there is no current produced by the closing of the circuit of the electro-magnet, is placed upon the disc, gives rise to a current, the intensity of which may be calculated by the method above mentioned; but, on the other hand, the sliding of the end of the wire upon the disc, in presence of the magnet, produces a current of a contrary direction; and, according to the result of experiment, we see that its intensity is the same as that of the former; and it is concluded from this, in a general manner, that the current, developed by the sliding of the extremity of the galvanometer, is equal to that which it would produce in the same wire, placed upon the curve described, by the closing of the circuit of the electro-magnet.

We have only spoken of the researches of M. Felici upon filiform circuits; he has extended his theory to bodies of three dimensions, by considering each point as the seat of an electro-motive force, producing an elementary current, which is diffused in the entire body. M. Felici, by applying calculation to the disc, rotating under the action of a magnet, has arrived at results conformable to those which M. Matteucci, in his special study upon this case of induction, has pointed out.

5.—*Improvements introduced into Induction Apparatus.*

Electro-dynamic induction, for some years past, has been the subject of numerous and interesting researches; and, since the publication of our First Volume, in which we have

treated of this branch of electricity, some new results have been arrived at, of which we think it useful to give here the analysis.

Ruhmkorff's Apparatus.

We have given the complete* description of Ruhmkorff's apparatus, including the improvements introduced by M. Fizeau, consisting of a condenser, the two plates of which communicate with the extremities of the inducing wire; but this apparatus, however simple it may appear in theory, frequently gave rise to difficulties, by the manner in which it acts under certain circumstances. The recent researches of M. Poggendorff† have caused these difficulties to disappear; and the complete analysis of what takes place in Ruhmkorff's apparatus has, moreover, the advantage of showing, in a logical manner, what is the best arrangement to be given to the various pieces of which it is composed. The following are the principal results of this work:—

The construction of the inducing helix gives rise to no important observation. The induced helix is not generally constructed in a suitable manner, in that it is formed of a great number of superposed layers, and that the two extremities of the wire are found at the same end of the helix, which causes the development of the two tensions, which are there contrary, and the greatest possible, to be necessarily interfered with. The best means for diminishing this inconvenience is to divide the helix into partial helices, each composed of an odd number of layers, which causes each of the two extremities of the wire to be at the two opposite ends. Besides, M. Poggendorff thinks that there would be an advantage in substituting an insulating liquid for a solid varnish; for, a spark, starting between two neighbouring spirals, would destroy the insulation in a temporary manner only.

The interrupter is generally set in motion by the bundle

* Vol. II. p. 23.

† Poggendorff, *Annalen*, t. xciv. p. 289. *Annales de Chim. et de Phys.* t. xliv. p. 375.

of iron wires that is situated in the helices. It is of advantage to make of this interrupter a distinct piece, set in motion by a special electro-magnet. M. Poggendorff made use of two different interrupters, one of which would have produced the interruption of the current in the interior of an insulating liquid; and the other consisted of an electro-magnet, rotating under the action of a horse-shoe magnet.

The condenser to which M. Poggendorff gives the preference is composed of a sheet of mica, covered with tin foil on its two faces; the difference of action of condensers resulting from the difference of their surface, is felt only when it is placed under conditions such that the extra-current in the inducing wire is energetic, that is to say, when a great number of elements and a long and fine wire are employed.

Three different cases may be distinguished in the mode of action of the apparatus:

First Case.—The induced circuit being closed by a solid or a liquid conductor, currents of directions alternately contrary are developed in it; the currents of opposed directions are equal in quantity, but different in duration.

Second Case.—The two extremities of the induced wire are separated by the air or by any gas. It then happens that the direct induced current is the only one that is developed, and that the induced helix presents two well-defined poles. In fact, the extremities of the induced wire being too far apart for sparks to be developed in them, if we bring an electroscope near to one of these extremities, it is charged with electricity of a constant nature, and the sign of which indicates that it results from the direct induced current. Besides, on bringing together the extremities of the wire, so as to produce sparks, we prove, either by the aid of the galvanometer or by electro-chemical processes, that they are due to the direct current.

This difference in the tension of the two induced currents may be explained in the following manner:—At the moment when the circuit is closed, the extra-current that is produced in it diminishes the tension of the inverse induced current: the direct induced current may be placed under analogous

conditions, by causing the principal current to pass through one only of the wires of the inducing helix, and by connecting the two extremities of the second; the induced current in this second wire then reacts upon the direct induced, so as to cause all spark to disappear.

M. Poggendorff has made several experiments, by plunging the interrupting apparatus into a liquid, and suppressing the condenser. In very good conducting liquids, only feeble sparks were obtained, on account of the influence of the extra-current, which could be freely established. With liquids completely insulating, the sparks were likewise feeble; for then the apparatus, deprived of the condenser, acted as in the air: but with badly-conducting liquids—alcohol, distilled water—the sparks were very powerful, the liquid here playing the part of a condenser.

These experiments led M. Poggendorff to place the interrupter in air rarefied to a pressure of 0·11 to 0·15 inches of mercury. The induction sparks became quite as strong as by the employment of the condenser: however, the sparks, always very powerful, that are produced in the interrupting apparatus, quickly alter the metallic surfaces.

Third Case.—The extremities of the induced wire are separated by a solid or liquid insulating medium. If the extremities of the induced circuit are wires of ordinary size, no phenomenon is produced; but if it is terminated by plates of a certain extent, separated by the non-conducting plate, this condenser is charged under the influence of each induced current, and is immediately discharged by the induced wire itself. No accumulation of electricity can be proved to exist on the plates; and noises are heard, which indicate the continual passage of electricity in one direction and the other,—between the plate and the insulating plate.

If, at the same time that the extremities of the induced wire are in communication with a condenser, its two coatings are made to communicate with two balls or points brought very near to each other, there pass between these two balls more powerful sparks than the ordinary induced sparks, which arises from the fact that the condenser, charged by the in-

duced current, discharges itself almost totally by these balls, on account of the great resistance of the induced wire.

The means of increasing the power of Ruhmkorff's apparatus has also been the subject of the researches of M. Foucault, who has conceived the ingenious idea of making several apparatus act simultaneously at the same time.* In fact, the obstacle that is always opposed to the increase of the energy of the induced sparks, is the difficulty of interrupting instantaneously the inducing current,—a difficulty which increases in proportion as the latter becomes more intense and the conducting wire longer. Now, if we succeed in arranging several inducing machines so as to act in a perfectly concordant manner, the spark of the extra-current in each of these will not be stronger than if it acted alone, and the power of the induced current will be increased proportionately to the number of apparatus.

M. Foucault has succeeded in obtaining the concordance of two apparatus in the following manner:—The current, setting out from the positive pole of the battery, penetrates, by bifurcating, into the inducing bobbins; each of the partial currents traverses an interrupter; they are then reunited, in order to return to the negative pole. In this manner the two machines are independent of each other; but we have merely to reunite the two partial circuits by a conductor communicating on either side with the inducing wire between the bobbin and the interrupter: agreement is then established, and the system acts with the power of a double machine. The induced sparks are noisy, sinuous, and 0·62 to 0·75 inches in length. In operating with two machines, it is necessary, in order to maintain the insulation of the induced wire, to establish the communications in such a manner that the positive and negative tensions accumulate at the outer and free extremities of the conductor; by operating with a greater number of machines, this insulation would present very great difficulties.

* *Comptes Rendus de l'Acad. des Sc.* t. xlii. p. 215. *Arch. des Sc. Phys. et Nat.* t. xxxi. of the Fourth Series, p. 243.

M. Foucault has added a new improvement* to Ruhmkorff's induction apparatus, by employing, as I had already done†, mercury as an interrupter; but covering its surface with a layer of alcohol, in order to prevent its oxidation, which would result from the heat produced in the air by the strong spark of the extra-current. An elastic plate of copper, bent and terminated by a platinum point, closes the inducing circuit sixty times per second, by penetrating by this point a greater number of times into the mercury. The contact that is then established is not the less perfect, notwithstanding its short duration. These contacts succeed each other at periods regularly distributed in time, as may be concluded by the persistence of the sound rendered, which is the same as that which is given out by the series of sparks that appear at the extremities of the induced wire. When he has several machines, they are united in pairs; the hammers are suppressed, and for them are substituted permanent conductors; the two inducing wires are united one after the other, and the interrupter is introduced into the circuit, accompanied by the condenser of the extra-current. For the sake of precaution, each machine must retain its discharge-wires, separated to the normal distance; they also each retain their commutators, which respectively serve to direct the two portions of the current in directions such that tensions of contrary signs accumulate at the internal extremities of the two induced wires; the latter finally being placed in communication, the external ends, which remain free, become the two poles of the system, and give sparks at the distance of an inch to an inch and a quarter, for two apparatus associated so as to form a pair. When we desire to place more than two machines under the control of the mercury-interrupter, it becomes necessary to insulate, with very particular care, these supernumerary apparatus, that is to say, to establish in these apparatus an absolute insulation between the inducing wire and the interior surface of the induced helix: this insulation is obtained in a complete manner by sliding a glass tube into the

* *Comptes Rendus de l'Acad. des Sc.* t. xliii. p. 44.
† Vol. I. pp. 301. and 383.

annular space by which the two concentric helices are separated. Starting from the moment when, by the care of M. Ruhmkorff, the condition has been fulfilled, four machines connected together, gave the effects of tension that might be expected from them; and the flow of sparks darted to the distance of about three inches. It is not necessary to dwell upon the remarkable effects that may be produced by means of so powerful an apparatus as this. The passage of these sparks, already so long, through the flame of a spirit-lamp, permits of our separating the electrodes still further, so as to obtain sparks much longer still; and which, by discharging through the vapour of alcohol, give out a peculiar sound, similar to that of a trumpet. The employment of the induction condenser communicates to the sparks a considerable illuminating power.

We must not forget to call to mind, in terminating the paragraph, that if it is M. Fizeau who conceived the idea of causing the two extremities of the inducing wire to communicate with the two armatures of a condenser, it is to Mr. Grove that we are indebted for the improvement, which consists in placing the two extremities of the induced wire also in communication with the two armatures of a condenser, such as a Leyden jar for example; there results from this, as we have seen, a considerable increase in the power of the sparks given by the induced wire. This phenomenon is the more remarkable, inasmuch as endeavours had been frequently made, but in vain, to charge an electric battery by the contact of its two armatures with the two extremities of an induced wire; but nothing beyond very feeble effects had ever been obtained, the electricity, communicated by the induced current to the battery, discharging itself through the induced wire itself. Here the discharge takes place, at least in great part, by traversing, under the form of a spark, the stratum of air that separates the two metal points that are near to each other, and communicating with the two coatings; if the discharge does not take place, at least entirely, through the induced wire, it is because this wire is

still subject to inducing actions, which are opposed to its serving as the return of the discharge.*

While this sheet was going through the press, Mr. Gassiot has completed a series of researches upon the light obtained from a powerful Ruhmkorff's coil in Torricellian vacuums, which he has communicated to the Royal Society. A vacuum of from one to twenty-eight inches was obtained. Mr. Gassiot found that, provided the glass tube was carefully cleaned, and care was taken to remove all traces of moisture, that the striæ in the positive discharge, originally noticed by Mr. Grove in the vapour of phosphorus, are invariably produced. The result to which he has arrived from his various experiments is, that the striæ or bands in the positive discharge, and the dark band between it and the negative, although apparently similar, are effects arising from different causes; the former from pulsations or impulses of force, acting on a highly attenuated but still resisting medium; the latter from interference.

6. — *New Researches on Diamagnetic Polarity and on Diamagnetism in general.*

In the theory that we have given of diamagnetism, in the Third Part of this Treatise †, by dwelling upon facts, we succeeded in admitting the existence of a diamagnetic polarity. The researches that have been made since that time come to confirm this conclusion, that we had deduced principally from Weber's experiments.

We had remarked that one of the principal arguments in favour of the hypothesis of the development of a special polarity in diamagnetic bodies was that the repulsion, exercised by an electro-magnet or by a magnet upon these bodies, varies proportionately with the square of the intensity of the magnetism; which proves, as I had remarked, that the diamagnetic body does not play a part purely passive in

* Vide *Phil. Mag.* vol ix. p. 1. (Jan. 1855), and *Ann. de Chim. et de Phys.* (New Series), t. xliii. p. 379.

† Vol. II. p. 47.

the phenomenon; but that it has its office, as well as the magnetized body, and, consequently, that it suffers an induction, analogous to, although not similar to, that which a magnetic body suffers, under like circumstances. The law that we have just recalled to mind, discovered by M. E. Becquerel, and confirmed by Prof. Tyndall, has just received a fresh confirmation from M. Reich, who, with this view, employed the great torsion balance, by means of which he had measured the mean density of the earth.* He suspended to the extremity of the horizontal lever of this balance a ball of bismuth, and he brought near to it, sometimes a magnetized bar, at other times an electro-magnet. The intensity of the magnetized bars was measured by the action which they exercised upon a small needle, placed at a great distance; the intensity of the electric magnet was regarded as proportional to that of the voltaic current; and the intensity of the repulsion was measured by the displacement of the arm of the lever of the balance. The repulsions observed varied almost as the square of the intensity of the magnetism, but without following exactly this law; a difference which may be explained, as M. Reich remarks, by the variation of the distance between the ball of bismuth and the magnet, which results from the movement itself of the balance.

Mr. Tyndall, in support of the conclusions already deduced from the experiments of M. Reich, had shown that when a diamagnetic body (a bar of bismuth), being movable, was suspended in the interior of a powerful magnetizing helix, its two extremities, when the pole of a magnetized bar was brought near to each of them, were seen to manifest properties exactly opposite to those which would have been manifested by the extremities of a bar of soft iron placed under the same conditions. It might be objected against Mr. Tyndall, that the movement of the bismuth placed in the interior of the magnetizing helix was not due to a repulsive action of the magnet upon a pole of the same name, created

* *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxi. p. 337.

in the piece of bismuth, but to a change in the direction of the forces which constitute the *magnetic field*, brought about by the presence of the magnet. It might be further objected against him, as had been done by M. Matteucci and Feitzlich, that the action of the magnet upon the diamagnetic body might be due to the production of induced currents, as Faraday has demonstrated in a series of experiments*; that, in order to avoid the production of these currents, and thus to prove that the effect observed is rather due to diamagnetic polarity, it would be necessary to employ, instead of diamagnetic conducting bodies, diamagnetic insulating bodies, or bodies reduced either into powder or into small fragments, in order to prevent the development of induced currents. In order to dissipate all doubts and to reply to all objections, Prof. Tyndall took up the entire question and succeeded, by means of numerous experiments, made with the greatest care, upon a system totally different from that which he had adopted in his former researches, in confirming, in a manner which appears to us unquestionable, the existence of the diamagnetic polarity that we had already admitted.†

The apparatus that Mr. Tyndall employed was constructed by M. Leyser, of Leipsic, according to the directions of M. Weber, who introduced some happy modifications into the apparatus, which had originally been employed by himself. It surpasses, in accuracy and sensibility, all those of the same kind that have been heretofore employed. This apparatus is composed essentially of two magnetizing helices, H E and H′ E′, which the current traverses in the same direction, and in the interior of which are situated two bars of the substance to be tested, acting upon an astatic system of two magnetized bars, the vertical projection of which is represented at N S; (*fig.* 442.) the horizontal projection at S N and N′ S′ (*fig.* 443.). The helices are nineteen inches in height, 0·8 in. in internal diameter; 1·3 in. in external diameter, and their axes are four inches distant from each

* See Vol. I. p. 464.

† *Phil. Trans.* vol. cxlvi. p. 237. (1856.) *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxii. p. 89.

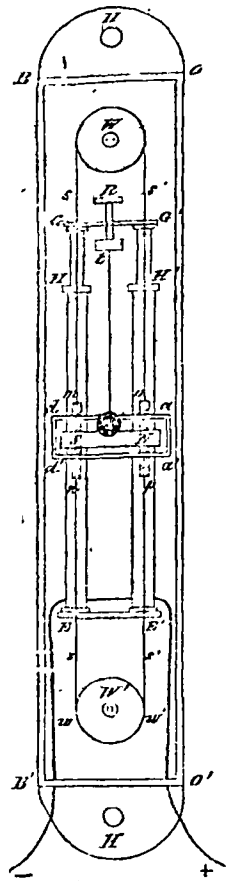

Fig. 442.

other. The copper wire, covered with silk, of which they are constituted, is coiled upon two brass reels, the upper extremities of which, G and G′, protrude a little above the upper extremities of the helices. The diamagnetic bars *m n* and *o p* are fixed to an endless cord *s s′*, which passes over the two pulleys W and W′, so that we can at pleasure place them both at the height of the middle of the helices, or displace them in the reverse direction, by equal quantities, starting from this position. The astatic system is composed of two equal magnetized bars, S N and S′ N′, (*fig.* 443.) situated in a semi-horizontal plane, and connected by a transverse brass rod, P, itself suspended by a bundle of silk threads, without torsion to the support R *t* (*fig.* 442.). The two bars are placed in the interior of a copper box, *a d a′d′*, which serves to arrest their oscillations; a mirror, represented by a black circle upon the figure, is invariably connected with the system; and the observation of the image of a divided scale reflected by the mirror allows of its smallest angular displacements being appreciated. In consequence of the arrangement of the apparatus, if the two helices and the two magnetized bars were perfectly identical, and if the two bars were situated exactly at the height of the middle of the helices, the actions of the helices upon the bars would produce equilibrium rigorously. This is never the case; and when, after having well adjusted the apparatus, without introducing diamagnetic bars into the axis of the helices, the current is made to pass, a slight deviation of the astatic system is always observed. The precaution is taken of destroying it by the

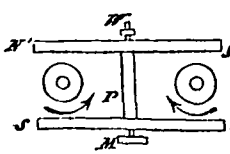

Fig. 443.

action of an auxiliary circuit, placed at some distance; and the diamagnetic bars are introduced only when the passage or the interruption of the current no longer determines any appreciable deviation. If the diamagnetic bars have the position indicated on the figure, that is to say, if their middles are exactly at the height of the axes of the magnets, the action of the bars upon the magnets is null; but if, by the movement of the pulleys W and W′, the opposite extremities *m n* and *o p* of the two diamagnetic bars are brought to be situated in the horizontal plane, which contains the axes of the magnets, it is easy to see that these extremities, being poles of contrary names, should exercise upon the astatic system concordant actions. We should therefore observe a deviation if these actions are sensible; and by substituting for the diamagnetic bars bars of soft iron, we can recognize whether the poles of the diamagnetic bodies are similar or contrary to those of the magnetic bodies. Experiment shows that, in all cases, they are contrary. We recognize also that all feebly magnetic substances, such as oxide of iron, sulphate of nickel, &c., act exactly in the same direction as soft iron; there is no difference, save in the extent of the action. It is essential, in these observations, to avoid all accidental deviations, due either to the agitation of the ground or to the currents of air that may exist in the box in which the entire apparatus is enclosed. This is accomplished by fixing the apparatus against a very firm vertical wall, taking the precaution of operating only at the hours when the ground of the neighbouring streets is not shaken by the passage of vehicles, and by introducing into the box cotton or pieces of paper, which do not allow of currents of air being established, while still leaving the motion of the magnetized bar perfectly free. It is not necessary to employ a very powerful battery for producing the current intended to traverse the helices; five Grove's pairs are sufficient.

Mr. Tyndall has made a great number of experiments*

* I have had the pleasure of being a witness of several of these experiments, either alone with Dr. Tyndall, or in presence of Drs. Faraday and Marcet.

with the apparatus that we have been describing, of which we will here transcribe some of the results. We designate by deviation the difference expressed in divisions of the graduated scale, at which the image is observed in the mirror, movable with the magnets between the two positions in which the astatic system is placed, when the bars, movable in the interior of the helices, are made to assume successively two positions symmetrical in respect to the horizontal plane, which contains the axes of the magnets. Thus, for example, with two cylinders of bismuth, three inches in length, and 0·7 inches in diameter, the position No. 1. (*fig.* 444.) corresponded to 670 divisions, and the position No. 2. (*fig.* 445.) to 630 divisions,

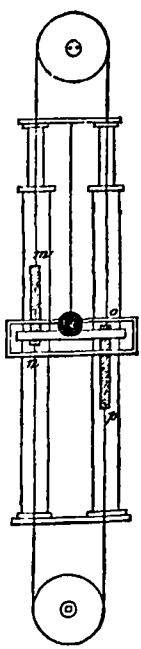

Fig. 444.

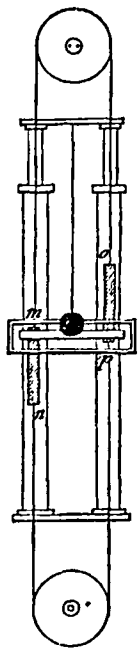

Fig. 445.

which gives a difference or deviation of forty divisions; the intermediate position of *fig.* 442. corresponded to 650 divisions. By changing the direction of the currents which traverse the helices, the direction of the deviation is changed, and consequently that of the diamagnetic polarity, which proves that the effect of the bars of bismuth upon the astatic system of

two magnets is actually due to the polarity that is developed in the bismuth by the currents. The position of equilibrium of the magnets being permanent, it is evident that the effect observed does not arise from induced currents; for these currents being only instantaneous, they could give only a jerk to the magnets, which would immediately return to their primitive position. Besides, if the induced currents counted for anything in the phenomenon, the latter would be much more decided with two copper cylinders, which, being forty times more conductive than those of bismuth, ought to possess induced currents much stronger. Now, precisely the contrary happens; for, with copper cylinders, we obtain an effect that is scarcely sensible; the deviation is at most one division. Finally, Prof. Tyndall has succeeded in demonstrating, in the same manner, the existence of diamagnetic polarity in insulating bodies, such as heavy glass, calcareous spar, &c., as well as in conducting bodies, such as the metals; which plainly proves that induction has no part in the experiments intended to demonstrate the existence of polarity; and that this latter is truly a molecular phenomenon. Bismuth powder, rammed in a glass cylinder, also presents diamagnetic polarity, although it is incapable of conducting an electric current: it is the same with several liquids likewise subjected to experiment, and which were contained in tubes of thin glass, closed at their extremities by means of well-cleaned corks.

In a first series of experiments, Mr. Tyndall obtained the following deviations with cylinders, 3 in. long and 0·7 in. diameter:—for *bismuth* 40, antimony 10, heavy glass* 4, calcareous spar 2. Copper gave only 1; and the direction of the deviation indicated that it had acquired magnetic, instead of diamagnetic poles. In a second series of experiments, Mr. Tyndall submitted to the action of his apparatus, magnetic as well as diamagnetic bodies; he has thus found very decided magnetic poles in solid perchloride of iron, car-

* The pieces of heavy glass, instead of having the form of cylinders, had that of a prism, 3 in. in length, 0·6 in. in width, and 0·5 in. in depth.

bonate of iron and sulphate of iron.* Solutions of sulphate of iron, chloride of cobalt and of nickel, also acquired magnetic poles. With regard to diamagnetic bodies, the following are the deviations that result from their polarity in this same series of experiments, in which the effects were more intense than in the former:—*solid bismuth* 75, *bismuth in powder* 37, *statuary marble* 5, *phosphorus* 4, *sulphur* 2, *nitre* 1·75, *wax* 1·25, *distilled water* 4, *sulphuret of carbon* 5·5.†

Although the existence of diamagnetic polarity appears to us to be firmly established by the labours of Mr. Tyndall, we should, however, add, that M. Matteucci, as the result of a very great number of experiments, made with helices, traversed by currents, and so arranged that the diamagnetic body was movable in one, whilst he acted with the other upon different points of the body, had arrived at the conclusion that all the movements of a diamagnetic body, in presence of two magnetic poles, might be explained without having recourse to the hypothesis of diamagnetic polarity; and he had besides remarked that the state of induction in diamagnetic bodies is not accompanied, as it is for magnetic bodies, by a reciprocal action between the elements, which give rise to polar resultants; and that, provided the dimensions of the diamagnetic bodies are great, the conditions that are induced in them by different centres of magnetic force are superposed in some sort, without disturbing each other. While still recognizing, with M. Matteucci, that diamagnetic polarity is not altogether of the same nature as magnetic‡, we cannot go so far as to question, as he does, the existence of the former, which the late experiments of Mr. Tyndall appear to us, as we have said, to have placed beyond doubt. Besides, we shall borrow from M. Matteucci himself some facts which, while perfectly reconcilable with the hypothesis

* The order in which the three salts of iron are placed, indicates the degree of energy of their magnetic polarity.

† The cylindrical dimensions given to the diamagnetic bodies, were not exactly the same for all; the most feeble were those of two cylinders of solid bismuth and bismuth in powder, which were 3 in. in length, and 0·7 in. in diameter, for each respectively.

‡ We have explained in what the polarities differ (Vol. ii p. 52, *et seq.*).

of polarity, are of a nature to throw fresh light upon the very interesting subject of diamagnetism. He has found that the state of division of diamagnetic bodies exercises no influence over their degree of diamagnetism, when these bodies are insulating, such as sulphur, stearine, &c.; whilst the diamagnetic power of conducting bodies notably increases with the degree of division of these bodies; and this the more as they are better conductors. This he has verified, especially for gold, silver, and copper. He has not found that bismuth in powder was more diamagnetic than bismuth in large fragments; it would rather be less so. We have seen that Prof. Tyndall has observed that the powder of bismuth produced in his apparatus a deviation much less than that to which similar cylinders of massive bismuth give rise. The state of division would not, therefore, increase the diamagnetism, except in bodies at the same time very little diamagnetic and very little conductors.

To these direct researches on diamagnetism, M. Matteucci has added others, intended, if it is possible, to seize upon some relations between diamagnetism and electro-dynamic induction. It is by trying the action of the rotating magnet upon mixtures of melted glue and very fine metallic powders, that he endeavoured to establish these relations. These mixtures, made either with gold or with copper, obtained in a very high state of division by chemical methods, are endowed with a diamagnetic power, which results from the sum of the diamagnetic powers of the quantities of resin and metal of which they are constituted. They likewise obey the action of the rotating magnet; and what is very astonishing is that, having passed beyond a certain limit of smallness, the finest powders rotate a little more rapidly than, or at least as rapidly as those which are less fine. Some parcels of a powder of gold, as fine as possible, fixed with gum-water to the extremity of a cotton thread delicately suspended, obeyed the action of the rotating magnet.* All these phenomena, developed in these divers cases by the rotating magnet, seem

* *Vide*, for these various labours of M. Matteucci, the *Comptes Rendus de l'Acad. des Sc.* t. xliv. pp. 242. 331. and 625.; t. xlv. p. 353.

to be still more favourable to the hypothesis of molecular electro-dynamic induction; but this induction would differ from diamagnetism, in that it could only be developed in bodies of a conducting nature; for, notwithstanding all his attempts, M. Matteucci has never been able to exert the slightest action with the rotating electro-magnet upon insulating diamagnetic bodies, whether in mass or in powder. Diamagnetism would, therefore, be the general fact; and electro-dynamic induction would be a property common to magnetic as to diamagnetic bodies, but being able to manifest itself only in such of these bodies as are of a conducting nature.

We shall not here return to the theory that we have given of magnetic and diamagnetic phenomena;* we think that the new facts, that we have just reported, are rather calculated to confirm it:—That molecular currents pre-exist in magnetic bodies, and that magnetization is only the result of a particular arrangement of the molecules of these bodies, which appear to us to result from the influence, always better established, of mechanical actions upon magnetism. With regard to diamagnetic bodies, the action of a current or of a magnet does not consist in giving to their particles a determinate direction; since these particles are not, like those of magnetic bodies, surrounded by pre-existing currents; but it is upon the atoms of which each particle is composed that the action is exerted; and this action, analogous to that which, in a body of finite size, constitutes electro-dynamic induction, determines around the particle a current, directed in the inverse direction to that with which we are acting. If the diamagnetic body is a conductor, we can conceive that it may happen that the molecular currents unite together at the first instant, so as to constitute an induced current, resulting from the rupture of equilibrium which existed in respect to the electric relation in the body; then, during the whole time that the action of the exterior current or magnet is lasting, a new equilibrium is established, in which the currents circulate around the molecule, which gives to the bodies diamag-

* Vol. II. p. 52, *et seq.*

netic properties. At the moment when, as the action ceases, this equilibrium ceases, a second induced current, similar to the first, but guided in a contrary direction, circulates in the body, but only so if the latter is a conductor. Thus, in all diamagnetic bodies, the exterior action of a magnet or of a current would be the same upon their molecules; but it would be accompanied, among such of them as are conductors, by a first current, induced at the moment when it commences, and by the second at the moment when it ceases. Might it not happen that, with those among them which are not conductors, the production of induced currents was replaced by that of some traces of electricity of tension? This would be an experiment worth trying, although, on account of the probable feebleness of the electric signs, it might present few chances of success. With regard to M. Matteucci's objection against diamagnetic polarity, derived from the fact that this polarity is not necessarily accompanied, like magnetic, with the existence of two opposite poles, it is easy to understand that this difference is due to the difference itself that exists between the two causes, of which one determines magnetism, and the other diamagnetism. The first being a common and concordant direction, given to pre-existent currents, the opposition of two poles is a forced result of this: the second being only the production of induced currents in each molecule submitted to external action, there are diamagnetic poles only in the points where the action is exercised; and if there is only one point, there is only one pole.

We shall confine ourselves, in terminating this subject, to mention yet some researches of MM. Plucker and Beer, upon the magnetic axes of crystals;* this subject has lost much of its interest, since Prof. Tyndall and M. Knoblauch have demonstrated that all magnetic crystalline phenomena are not connected with a new principle, but are merely the result of the influence of molecular structure upon magnetic or diamagnetic bodies, and that they simply depend upon the laws which govern magnetism or diamagnetism, only with the difference, that in crystallized bodies the polarity tends to

* *Annales de Chim. et de Phys.* (New Series), t. xlix. p. 221.

develope itself, according to certain fixed directions, whilst in non-crystallized bodies the direction of the line of the poles is determined only by the form of the bodies. MM. Plucker and Beer have submitted to experiment a very great number of crystals, both magnetic as well as diamagnetic, belonging to the different systems of one axis and two axes. Their results are especially interesting for crystallography; for they obtain, by the study of magnetic action, a new element, to be added to all those deduced from optical phenomena, of conductibility for heat, for electricity, and others besides, which serve to give an idea of the arrangement of particles in crystals. Mr. Faraday has likewise taken up the same subject*, but with the view of studying the influence of temperature upon the magneto-crystalline force; and he has succeeded in finding that, under the same circumstances, the force of direction of crystallized bodies, as well diamagnetic as magnetic, diminishes sensibly with elevation of temperature. This result was more easy to determine upon crystallized bodies than upon those which are not so, because the directive force of the crystal, as well of that which is diamagnetic as of that which is magnetic, not being influenced by the surrounding medium, as is the case when the body is not crystallized, we are easily able to raise the temperature of the crystal by placing it in a liquid medium which is heated without the presence of this medium modifying its directive force, otherwise than by the influence of change of temperature.

7.—*Optical Properties of transparent Bodies, subjected to the Action of Magnetism.*

Since the publication of the First Volume of this Treatise, in which we had made known the phenomena of circular magnetic polarization†, this subject has been submitted, by M. Verdet, to an examination as profound as detailed.‡ By means of a very powerful electro-magnet, and very wide

* *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxii. p. 55.
† Vol. I. p. 497.
‡ *Annales de Chim. et de Phys.* (New Series), t. xli. p. 370.; t. xlii. p. 37.

armatures, so as to have a large magnetic field of equal intensity, M. Verdet succeeded in determining the laws of the phenomena. He first found that there was a proportionality between the rotation of the plane of polarization and the intensity of the magnetic force; he measured this latter by means of the induction current, developed in a bobbin placed in the magnetic field, to which a motion is imparted that renders its plane perpendicular to the line of the poles from the parallel position in which it was. M. Wiedemann* had already demonstrated that the rotation produced by electric currents, without the intervention of magnetism, is proportional to the intensity of these currents. The experiments that have enabled M. Verdet to establish his law were made in very great number upon heavy glass—ordinary flint—and sulphuret of carbon. The same philosopher then considered the phenomena, which take place when the direction of the luminous ray makes any angle with the direction of the magnetic action; and he found that the rotation is proportional to the co-sine of the angle, comprised between the two directions, and consequently to the component of the magnetic action, parallel to the ray of light: he extended his experiments, which were directed to the three same substances, as far as angles of 80°, comprised between the direction of the luminous ray and that of the magnetic action.

In ulterior researches† M. Verdet has endeavoured to determine, by means of the same very perfect apparatus which had enabled him to find the laws that we have pointed out, the magnetic rotatory powers of different substances. He has not found that there existed, as I had thought‡, any relation between the refracting power or index of refraction of the different substances tried, and their rotatory magnetic power. Thus the mean index of refraction being for *water* 1·3341, for *concentrated proto-chloride of tin* 1·426, and for *nitrate of ammonia* 1·448; their rotatory magnetic powers are respectively 4°·00, 8°·16, and 3°·44.

* *Ann. de Chim. et de Phys.* (New Series), t. xxxiv. p. 121.

† *Comptes Rendus de l'Acad. des Sc.*, t. xliii. p. 529.; t. xliv. p. 1209.; t. xlv. p. 33.

‡ Vol. I. p. 523.

Among the substances submitted to experiment by M. Verdet, solutions of salts of iron, and of other magnetic metals, presented to him very remarkable phenomena. Thus, the presence of a salt of iron in water not only does not increase its rotatory magnetic power, but diminishes it; an effect which arises, as it is easy to prove, from the fact that the salts of iron exercise, under the influence of magnetism, upon polarized light, a contrary action to that which is exercised, under the same circumstances, by water, glass, sulphuret of carbon, and other transparent substances in general.* This property is designated under the name of *negative* magnetic rotatory power by M. Verdet, who gives the denomination of *positive* to that of other substances; in fact, water, sulphuret of carbon, and glass cause the plane of polarization to rotate in the direction in which the positive electricity traverses the conducting wire of the electro-magnet; whilst the salts of iron cause it to rotate in the direction of movement of the negative electricity. The salts of protoxide of iron have not a negative rotatory power sufficiently great to cause the positive rotatory power of the water entirely to disappear; whilst an aqueous solution, that contains 40 per cent. of per-chloride of iron, exercises over polarized light an action contrary to that of water, and six or seven times greater. The ethereal and alcoholic solutions give the same results. The most suitable solvent is pyroligneous spirit, which is able to charge itself with a considerable quantity of the salt of iron, while remaining much more transparent than water, ether, or alcohol, charged with the same proportion of salt; 55 parts of per-chloride of iron, dissolved in 45 parts of pyroligneous spirit, give a very transparent liquid, the rotatory action of which upon polarized light is almost double that of heavy glass, but in a con-

* It was by trying solutions of iron of different natures, alcoholic, ethereal, as well as aqueous, that M. Verdet satisfied himself that it is indeed to the salt dissolved that we must attribute the diminution, which is always the same from a same quantity of iron, which is suffered by the rotatory power of the substance that serves as a solvent. It is therefore truly to a rotatory power, in a contrary direction to that of the solvent, possessed by the dissolved salt of iron, that the diminution observed must be attributed.

trary direction; this liquid has served M. Verdet to satisfy himself that the laws which govern the negative rotation produced by the salts of iron, are the same as for the positive rotation produced by the generality of transparent substances.

A curious fact is, that all the salts of nickel, contrary to those of iron, have a positive rotatory power, so that their solutions exercise over polarized light a much greater action than that of the water which they contain. Trials upon the salts of cobalt, and the other magnetic metals, have led M. Verdet to divide these metals, in respect to the properties which they communicate to their transparent compounds, into two classes, one of which includes iron, chromium, titanium, cerium, uranium, and lanthanum; the other, nickel, cobalt, and molybdenum. The salts of the former metals all possess a negative rotatory power, and are in general magnetic; those of the latter a positive power, and several among them diamagnetic. Manganese should be classed in the latter category; for its compounds acquire, under the influence of magnetism, a positive rotatory power; but there exists a compound, the double cyanide of manganese and potassium, which has a negative rotatory magnetic power.* It is very remarkable, that the corresponding compound of iron, namely, the *yellow* cyanide of potassium and iron, has a positive rotatory power, whilst all the other compounds of iron, including the *red* cyanide of potassium and iron, have a negative power. We may add, that the yellow cyanide is diamagnetic, whilst the red is magnetic. The double cyanides of nickel and cobalt have a positive rotatory power; the latter is even diamagnetic. Nitrate of uranium is diamagnetic, when it has been brought to a great state of purity by successive crystallizations; but the red and the black oxides of uranium are both of them magnetic. Perfectly pure carbonate of lanthanum is magnetic. Molybdenum and mo-

* Manganese seems to represent the link between the two classes of magnetic metals: that which is the rule for compounds of iron, is the exception for compounds of manganese, and *vice versâ*.

lybdic acid are magnetic; but the molybdates of soda and ammonia are diamagnetic.*

8.—*Reduction of the Measures of Intensity of Currents to Mechanical Units, by MM. Weber and Kohlrausch.*†

The intensity of currents is measured by their electro-magnetic, their chemical, and sometimes their electro-dynamic action, which we know to be proportional; but, in general, we content ourselves with employing that one of these three processes which appears to be the most appropriate to the experiments that we have in view, in order to compare the intensities of one series of currents, without distressing ourselves, in order to obtain absolute measures, founded upon a definite system of units, independently of the particular apparatus that are made use of. M. Weber has been greatly occupied in the establishment of these absolute measures, and he has proposed a system of units, analogous to the system of units introduced by Gauss in the measure of magnetic actions.

We know that, according to Gauss, the unit of magnetic fluid is the quantity of fluid which, being concentrated upon a point, and acting upon an equal quantity of the same fluid, similarly concentrated in a point and placed at the unit of distance, exercises a repulsion equal to the unit of force. (The unit of distance and the unit of weight adopted by Gauss are the millimètre and the milligramme.)

The unit of electro-magnetic intensity, proposed by M. Weber, is the intensity of a current which, traversing a circular conductor, the area of which is equal to the unit of surface, and acting upon a magnet, the magnetic moment of which is equal to the unit, placed at a very great distance, so that its

* The greater portion of the specimens of which M. Verdet made use, were prepared in the chemical laboratory of the Normal School, under the direction of M. Deville, which is a guarantee of their perfect purity. It is also to specimens furnished by the distinguished chemists who work in the same laboratory, M. Troost and M. Debray, that M. Verdet is indebted for having been able to prove that lithium and glucinum, as well as their compounds, are diamagnetic.

† *Mémoires de la Société Royale de Saxe*, t. v. p. 221. *Annales de Chim. et de Phys.* t. xlix. p. 115.

axis is parallel to the plane of the circular conductor, and that its middle is situated upon the perpendicular to this plane, drawn through the centre of the conductor, gives rise to a pair, the moment of which is equal to the unit divided by the cube of the distance from the middle of the magnet to the centre of the conductor.

The unit of electro-dynamic intensity is the intensity of the current which, traversing a circular conductor whose area is equal to the unit, and acting upon an equal current which traverses another circular conductor, identical to the preceding, and placed at a very great distance, so that its plane is perpendicular to that of the former conductor, and that the intersection of the two planes is a diameter of the former conductor, gives rise to a pair, the moment of which is equal to the unit divided by the cube of the distance of the centres of the two conductors.

The unit of electro-chemical intensity is the intensity of a current which, traversing a voltameter, decomposes, during the unit of time, the unit of weight of water, or an equivalent quantity of any electrolyte. The unit of electro-chemical intensity is to the unit of electro-magnetic intensity as 106·66 is to 1.

Establishing also an absolute measure for static electricity, by taking for the unit of electric fluid the quantity which, being concentrated in a point and acting upon an equal quantity of the same fluid, similarly concentrated in a point, and placed at the unit of distance, exercises a repulsion equal to the unit of force, M. Weber, in concert with M. Kohlrausch, has occupied himself in determining the absolute quantity of electricity which traverses, during the unit of time, any section of a conductor in which a current is circulating of an intensity equal to the unit. The method which they have followed consists in determining the intensity and the duration of the current which gives to the needle of a galvanometer the same impulse as the discharge of a given quantity of electricity.

Without entering into the detail of the experiments, we will here point out the order of the operations.

We measure the fraction of the charge of the inner coating of a Leyden jar which this coating communicates to a metal sphere that is placed in contact with it; and, for this purpose, the inner coating of the jar is placed in communication with an electrometer, before and after a given number of contacts of the sphere.

Then, we measure simultaneously the impulse given to the needle of the galvanometer by the discharge of the Leyden jar, and the action that is excited between the balls of the torsion balance, charged with a known fraction of the electricity of the jar. For this purpose, after having charged the jar, its inner coating is touched with the metal sphere, of which we have spoken; and this sphere, being placed in contact with the fixed ball of the torsion balance, communicates a fraction of its electric charge, which may be determined by knowing the diameter of the two spheres. The torsion balance gives the absolute measure of the electricity of the fixed ball; and we may calculate from that the amount of the electricity of the jar, taking account also of the loss that takes place between the moment in which it has been placed in contact with the metal sphere, and that in which it is discharged. A second observer discharges the jar after a given number of seconds, setting out from the moment of contact; and he notes the amplitude of the deviation of the needle.

It only remains now to determine the duration, T, which a current should have of intensity equal to the electromagnetic unit, in order to give to the needle the same velocity as is given to it by the instantaneous passage of the quantity of electricity, E, previously measured. We may conclude from this, that when this current traverses a wire, there passes during a time, T, through a given section of this wire, a quantity of electricity equal to E; and as the current is constituted by the movement of equal quantities of the positive and negative fluid travelling in contrary directions, this amounts to saying that, during the time T, a section of the wire is traversed by a quantity $\frac{E}{2}$ of positive electricity in

one direction, and by a quantity $\frac{E}{2}$ of negative electricity in the other. During the unit of time, there will pass through each section of the wire a quantity $\frac{E}{2T}$ of positive fluid, and an equal quantity of negative fluid.

In order to calculate this duration, T, the experimental data are the angle of deviation of the needle of the galvanometer under the action of the electricity E, and the constants of the apparatus, relative either to the needle itself, or to its suspension thread.

MM. Weber and Kohlrausch have executed five series of experiments, which have given to them as a mean, for the value of $\frac{E}{2T}$ the number 155,370,000,000. Thus, for each section of a wire, in which is circulating a current of intensity equal to the electro-magnetic unit, there passes during the unit of time 155,370 millions of units of positive electricity, and an equal quantity of negative electricity, travelling in the contrary direction.

9. — *Researches relative to Conductibility.*

The study of the propagation of electricity in conducting bodies, and the determination of electric conductibility, which is intimately connected therewith, is one of the subjects which have most engaged the attention of philosophers, both on account of its theoretical importance, as well as on account of the practical application which it presents. We have already made known many works among those which have for their subject these questions;* and yet, since the publication of our Second Volume, fresh researches have appeared, among which we have distinguished those of MM. Mousson, Thompson, and Matthiessen.

M. Mousson†, struck by the differences that are presented by the results obtained by various experimenters in the de-

* Vol. II., p. 201., *et seq.*

† *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxi. p. 111.

termination of the resistances of the different metals, although the object of this determination is one of the most simple phenomena, since it is not complicated either by chemical decompositions or by the transport of particles, has desired to attempt to analyse the causes of these divergences. The process employed for measuring the resistances of the wires submitted to experiment was the following:—The current coming from a single Daniell's pair, feebly charged, bifurcated, after having passed through a tangent galvanometer, traversing on the one side the wire upon which the examination was directed, and on the other the wire of a rheostat. It then traversed the points of derivation of the galvanic bridge*, afterwards traversed the identical parts of the branches, and was confounded anew in the wire which returned to the pair. The influence of the nature of the contact upon the resistance is very decided; junctions by soldering or by immersion in mercury with amalgamation are those which do not appear to produce any appreciable resistance; simple contact, even with pressure, offers one which is greater in proportion as the pressure is less. The influence of a surrounding liquid upon the conductibility of a wire is almost null, except that there results from it a diminution of resistance by the simple fact of cooling, produced by the immersion of the wire in the liquid. Tension sensibly increases the resistance of a wire to conductibility, not only because it diminishes its diameter and increases its length, but also in a *more direct manner;* for the mere changes of dimension are not sufficient to explain this influence. On the other hand, shaking or vibrations imparted to a steel and to a copper wire, in no way modify their conductibility. The influence of diameter, although brought under a very simple law, which has been verified by a great number of philosophers, has presented to M. Mousson an anomaly, which consists in a constant resistance, indepen-

* The galvanometer is placed upon this direct communication between the two branches, which is termed the *galvanic bridge*; and, if care is taken to construct of two identical wires the two parts of the branches that meet together at the point of derivation of the bridge, the needle of the galvanometer will not be able to remain in equilibrio, except so long as the two first parts of the branches shall present identical resistances.

dently of the diameter of the wires, and which is probably due to an effect which takes place at the extremities where the current enters or comes out. The configuration of a wire, inasmuch as it modifies its internal constitution, reacts upon its resistance to conductibility in proportion to the size and extent of the alteration; but the coiling of a wire, even in the ductile state, is constantly accompanied by molecular changes, which frequently produce a very sensible increase of the resistance. *Hammer-hardening, tempering, annealing,* three operations which deeply alter the internal nature of wires, modify their resistance quite as powerfully; this had been already observed by MM. Pouillet and E. Becquerel. M. Mousson, in confirming the results obtained by these two philosophers, has added to them a curious observation; it is that copper, hardened by the draw plate, undergoes, like steel coming out of the draw plate, an increase of resistance by annealing. The effect of tempering is altogether different, since the resistance of steel, compared with what it was in the annealed state, increases nearly one-fourth; whilst that of copper diminishes, but by one-fourth only. The influence of temperature has been, on the part of M. Mousson, the subject of very numerous and very careful experiments; he likewise has found the laws, laid down by M. E. Becquerel and M. Lenz, defective. The former admitted, up to 392°, the proportionality between the increase of resistance and that of temperature; now, the co-efficient, which represents the relation of these two augmentations, itself increases even below 392° in a very evident manner. The latter deduced, as a consequence of his formulæ, the existence of a *maximum of resistance* at a particular temperature for each metal: now, experiment has given to M. Mousson, for iron, a progression continually ascending up to the highest incandescence that a good blow-pipe was capable of producing. Thus, all things considered, the exponential law is that which, in the present state of our knowledge, best corresponds to observations. M. Mousson terminates his work by a study of the rheostat, the employment of which, in his opinion, must be accompanied with great precaution, if we desire to avoid the grave errors

to which the various influences that he has studied may give rise.

M. Mousson had not found that magnetism exercised any influence over the electric conductibility of iron. Dr. Thompson, in a study upon the electro-dynamic properties of metals*, succeeded in showing that magnetization in the direction of length diminishes the electric conductibility of iron, and that this conductibility is greater perpendicular than parallel to the lines of magnetization, which is in accordance with the molecular phenomena that accompany magnetization; since, by this action, the particles are separated in the longitudinal direction, and approximated in the transverse direction.

We have described, in our second volume, the processes of M. Becquerel and of M. Pouillet for measuring the conductibility of the different metals; these processes rest upon the employment of the differential galvanometer, which enables us to determine what is the length of the type wire, the resistance of which is equivalent to that of the wire, whose electric conductibility is being sought. The employment of the differential galvanometer presents very great difficulties, which a method, invented by M. Kirchoff completely banishes. This method, the description of which will be received with pleasure, is founded upon a particular case of derived currents,—that in which the intensity of the current in a derivation wire is null, in consequence of the values that are given to the resistances of certain parts of the circuit. Let P (*fig.* 446.) be, in fact, a battery, the poles of which are united by the conductor *p a d b*; *a b* is a derivation wire, and *c d* a conductor, which connects the two derived currents; the resistances and intensities are designated in the five branches of the circuit, which we have to consider by the letters λ and *i*.

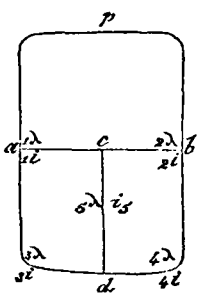

Fig. 446.

* *Phil. Trans.*, Vol. 146. Part III. p. 649. — 1856.

According to Kirchoff's laws, of which we have already spoken*, on the general theory of derived currents, the following relations may be established:

$$i = i_2 + i_5;$$
$$i_3 = i_5 + i_4;$$
$$i_3 \lambda_3 + i_, \lambda_, + i_5 \lambda_5 = 0;$$
$$i_2 \lambda_2 + i_4 \lambda_4 + i_5 \lambda_4 = 0.$$

By means of these four equations we are able to express i_5 in a function of one only of the other intensities, i_3, for example; and, by eliminating the others, we easily find:

$$i_5 (\lambda_, \lambda_5 + \lambda_, \lambda_4 - \lambda_, \lambda_2 - \lambda_4 \lambda_5) = i_3 (\lambda_2 \lambda_3 - \lambda_, \lambda_4).$$

Consequently, whatever may be the value of i_3, if the resistances $\lambda_, \lambda_2 \lambda_3 \lambda_4$ satisfy the relation $\lambda_2 \lambda_3 = \lambda_, \lambda_4$, the intensity i_5 is null; that is to say, that no current passes in the conductor *c d*.

Let us now introduce a galvanometer into *c d*, then into *b d*, the wire to be experimented upon, the unknown resistance of which is x, as well as that of a rheostat; by means of this latter instrument, λ_4 is made to vary, until its value satisfies the above relation, which is indicated by the galvanometer; the needle of which is brought back to 0°. The wire is then removed, and the needle of the galvanometer, by the aid of the rheostat, is again brought back to 0°. The length of wire that it has been necessary to add gives the value of x, the resistance sought.†

* Vol. II. p. 893.

† M. Quincke (*Ann. der Poggendorff*, t. xcvii. p. 382., March, 1856; and *Ann. de Ch. et de Phys.*, t. xlvii. p. 203.), in a Memoir upon the propagation of electricity in metal plates, proposed to verify by experiment the theory of M. Kirchoff (Vol. II., p. 893)., which this philosopher had submitted to experiment only in the case of a circular plate, communicating by two points of its circumference with the electrodes of a battery. M. Quincke has examined two other cases a little less simple, and has found, as does M. Kirchoff, a very satisfactory agreement between experiment and theory. The first case is that of a square plate, in which the electricity arrives by one of the summits, and by a point taken upon the diagonal, which passes through this summit. The second case is that of an heterogeneous plate, composed of a semicircular plate of lead, and a semicircular plate of copper, soldered together according to their common diameter, the electrodes of the battery communicating with two points of the circumference of the same semicircular plate, situated at equal distances from the line of soldering. M. Quincke has been able, from the summary of his experiments in this latter case, which gave him lines of

M. Matthiessen* has applied M. Kirchoff's method to the determination of the electric conductibility of some of the most oxidizable metals, the physical properties of which have been in a condition to be studied subsequently to the advances that have been realised in their preparation. It was in M. Kirchoff's laboratory at Heidelberg that M. Matthiessen made his experiments.

The principal difficulty that was presented by these researches was the fabrication of fine and homogeneous wires of these metals. M. Matthiessen has surmounted it by causing the metals to pass through the draw-plate by pressure instead of operating by traction, as is ordinarily done. The metal was introduced into a small cylindro-conical cavity, formed in a piece of steel, presenting at the summit of the cone by which it was terminated a small opening. Into this cavity was thrust a steel piston of the same form; and, by exerting a sufficient pressure upon this piston, the metal was made to come out by the orifice of the cavity under the form of a wire. In the case of potassium, sodium, and lithium, which are at once very ductile and very oxidizable, the operation took place in oil of naphtha. In the case of magnesium, which is very little ductile and very little oxidizable, the press was heated by the aid of a jeweller's lamp; and consequently, the operation was carried on in the air. Finally, in the case of strontium and calcium, which are not more ductile than magnesium, but much more oxidizable, the press was heated, and the wire immediately on its coming out was received in a tube full of oil of naphtha.

The resistances, as we have said, were measured by M. Kirchoff's method. The wire of comparison was a copper wire, the conductibility of which had been carefully com-

equal tension of the plate of lead and the plate of copper, to calculate the relations of conductibility of the lead and copper that he had employed in his researches. This relation was that of 12·47 to 100. The method employed by M. Quincke for lead and copper, might likewise serve to etdermine in a very exact manner, and without having need to reduce them into wires, the relation of conductibility of various other metals with copper. We know not whether it has been put into practice in other cases besides that which we have just quoted.

* *Phil. Mag.*, 4th Series, vol. xiii., p. 81.; *Ann. de Ch. et de Phys.* t. l. p. 192.

pared with that of silver. Designating that of silver by 100, M. Matthiessen found the following numbers: —

Sodium	37·43	at the temperature of	71°
Magnesium	25·47	„	62·6
Calcium	22·14	„	62·25
Potassium	20·85	„	68·72
Lithium	19·00	„	68
Strontium	6·71	„	68

The numbers, relative to potassium and sodium, alone present a little doubt, on account of the rapid oxidation of these metals.

M. Matthiessen has studied the influence of temperature upon the conductibility of potassium and sodium; these metals were melted in glass tubes, plunged into a solution of chloride of calcium, and communicated with the exterior only by small columns of mercury. The conductibility of these metals diminishes when the temperature rises; and it is much more feeble in the liquid than in the solid state. For sodium there is a sudden leap at the fusion temperature of 200°; for potassium there is a very rapid variation between 116·6° and 134·6°, but no sudden leap.

10.—*New Experiments for proving that the Transmission of Electricity through Liquids is always accompanied by their electrolytic Decomposition.*

The opinion that compound liquids are able to conduct electricity, after the manner of solid conducting bodies, without being consequently decomposed, had not appeared to us to be able to be adopted, notwithstanding the imposing authority of Faraday.* The illustrious philosopher had particularly invoked in favour of this opinion the fact that water comports itself like metals in the phenomena of static electricity. Now, three philosophers have shown that, even when this electricity is in question, the electric propagation in a liquid is accompanied by its decomposition.

* Vol. II. pp. 376. and 421.

Mr. Andrews*, by means of a very simple contrivance, has obtained the polar decomposition of water with a common electric machine; this contrivance consists in collecting the gases in capillary tubes, into which very fine platinum wires penetrate through the closed extremity, which withdraws these gases from the dissolving action that takes place when the electrodes plunge into a large mass of water. If the tubes are graduated, we recognise that the volumes of the two gases are truly in the relation of 1 to 2,—and it is easy to prove that one is oxygen and the other hydrogen. A plate machine, making 240 revolutions per minute, liberated during this time about 0·00000396 cubic inch of oxygen. By means of a kite Mr. Andrews employed atmospheric electricity for performing the same experiment; and he obtained in an hour, during weather that was serene and not at all stormy, 0·00000324 cubic inch.

M. Buff, who had already succeeded in rendering the decomposition of water apparent, even with an excessively feeble current, by employing platinum wires, soldered in tubes of glass, so that the extreme metal point alone was bare†, had likewise established the proportionality between the quantity of water decomposed and the intensity of the current, even when the quantity of hydrogen liberated in an hour only reached to 0·00254 cubic inch. In order to confirm the conclusion, contrary to the idea of the physical conductibility of liquids, which he had already deduced from his former experiments, he made fresh researches‡ by employing the electricity of ordinary electrical machines; by this means he obtained the polar decomposition of water, as Mr. Andrews had done; and more than this, that of dissolved sulphate of copper. He then made two platinum points after Wollaston's arrangement, plunging below under two bell glasses filled with water, placed in the same vessel, to communicate, one with the positive conductor, the other with the negative of the electrical machine; the bell glasses were furnished in

* *Annales de Ch. et de Phys.* (N. S.), t. l. p. 124.
† *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxix. p. 118.
‡ Idem, t. xxxi. p. 198.

their upper part with platinum points, which enabled their being used as eudiometers, in order that he might prove whether the gaseous products were a mixture of oxygen and hydrogen, or these two gases separated. He has proved that the two gases were separate, and were found in each tube in the proportion that constitutes water; then, having caused the same discharge to pass successively through two voltameters, one filled with pure water, the other with sulphuric acid, diluted to the density of 1·15, he obtained, after having caused the machine to turn for 90 minutes, 0·0016772 cubic inch hydrogen in the acidulated water, and 0·001636 cubic inch in the pure water, which makes only a very small difference, easily explicable by the greater solubility of the gases in pure water. The result is no longer the same when, instead of placing the points directly in communication with the electric machine, we allow an interruption in the circuit, and the electricity traverses this space under the form of sparks; then the quantities of gas collected are more considerable at the negative electrodes, and oxygen and hydrogen are there mixed together; however, after having obtained a diminution of volume by causing an electric spark to pass through the gaseous mixture, an excess of hydrogen is found, which proves that polar decomposition has likewise taken place, but that calorific decomposition is added to it; the former of the decompositions is proportional to the intensity of the current, whilst the latter depends upon the rapidity with which the electricity is able to overcome the resistance of the liquid,—a resistance which brings about a considerable elevation of temperature. The calorific decomposition is more abundant in pure water than in acidulated water, on account of the greater development of heat, which takes place in the former at the point of contact of the electrode and the liquid; whilst the electrolytic decomposition is the same in both liquids. A slight liberation of light is always remarked at the extremity of the points plunged in the water, when, from the circuit's not being continuous, we obtain calorific decomposition; and we likewise observe, in this case, that the electrodes are polarized, because electrolytic decomposition

likewise takes place. A pretty experiment of M. Buff's, which shows that electrolytic decomposition takes place as well when there is only one metal electrode, as when there are two, consists in taking a tube, closed above, with a platinum point that penetrates into the hydrogen with which this tube is half filled, whilst the other portion, filled with water, communicates with the external water; the platinum point is made to communicate, sometimes with the negative conductor, sometimes with the positive conductor of the electric machine, whilst the water communicates with the ground. If the machine is made to act for some time, we see, in the former case, the volume of hydrogen increase,—a proof that this gas is liberated at the contact with the water; and, in the latter case, the volume diminishes, because it is oxygen that is liberated. We even obtain an evident decomposition by placing the water in communication with the positive conductor of the machine, by the intervention of a Wollaston point, and by merely bringing near to the surface of water the hand or any other conductor, which is held at a sufficiently great distance, so that there may be no sparks. Evidently, in this case, as in the preceding one, the air or the gas plays the part of negative electrode, and produces a liberation of gas upon all the points of the surface of the water.

It is not only when electricity travels under the form of a discharge through the water, that its propagation is accompanied by the decomposition of this liquid, there is also an electrolytic action, when the electricity is set in motion by an effect of induction. M. Soret has proved this* in an experiment, of which he conceived the idea, and which I realized with him: it consists in taking pure water for the internal and external coatings of a Leyden jar, the insulating substance of which is formed by a very high glass bottle, carefully varnished within and without, in order that the insulation may be perfect. At the bottom of this bottle is introduced a certain quantity of water, which is to serve as an inner coat-

* *Arch. des Sc. Phys.*, t. xxxi. p. 204.

ing, and into which the positive electricity of an electric machine is made to arrive by means of a brass chain. The water that serves as the outer coating is enclosed in a glass vessel well insulated, in the centre of which is placed the bottle that fulfils the office of insulating layer; into this water are plunged two perfectly cleaned plates of platinum, each soldered to a wire of the same metal, and supported by glass rods, resting upon the edges of the vessel. We commence by proving that there is no production of any current, by placing the two platinum plates in communication with the two ends of a very sensitive galvanometer; then, after having detached the wires from the galvanometer, one of the plates of platinum is placed in communication with the ground, and the electric machine is made to act. After three turns of the plate, the communication of the plate with the ground is interrupted; and the jar is discharged by plunging into the water of the outer vessel the end of a bent brass rod, and by touching with the other extremity the metal chain that is plunged into the water of the internal vessel. The brass rod is then removed; the communication of the platinum plate with the ground is re-established, and the operation of charging is again commenced. In several experiments, sixteen consecutive charges and discharges were accomplished; which required forty-eight turns of the plate. When, after these sixteen charges, the platinum plates were placed in communication with the wires of the galvanometer, a current was observed, which caused the needle to deviate about 25° to 30°. The direction of the current indicated that it was the platinum plate, communicating with the ground, that had been positively polarized, and upon which, consequently, hydrogen was deposited; which, in fact, should be the case, since the positive electricity, decomposed by induction, would go by this plate into the ground. The experiment was repeated a great number of times, and constantly gave the same results; every precaution had been taken in order to avoid all escape of electricity along the sides of the glass of the bottle; and we satisfied ourselves, in a direct manner, that this escape had not taken place. It is a very remarkable thing to obtain an electrolytic

decomposition with a single electrode; it is probable that, while hydrogen is liberated at the surface of the platinum plate, by which the positive electricity escapes into the ground, there is a liberation of oxygen at the surface of the water in contact with the insulating layer. Besides, we may easily prove that the polarization of the electrode, and consequently, the electrolytic decomposition, is as powerful when there is only one electrode as when there are two. For this purpose we have merely to transmit, by means of two fresh platinum plates, similar to the former, through the water contained in a second glass bottle, the positive electricity which, coming out of the water of the former, went into the ground; and by successively connecting with the galvanometer the two pairs of platinum plates, we find very sensibly the same deviation of the needle for each, when the sixteen consecutive discharges are produced.

We should also mention the experiments by which M. Despretz had thought that he had found that a feeble voltaic current could be transmitted through water without decomposing it*; but, we should add, that MM. Logemann and Van-Breda† have demonstrated that, in this case, as in other similar ones, the electrolytic decomposition, although not apparent, did indeed take place, since the electrodes were always polarized.

11.—*Phenomena of Transport in Electrolysis.*

There are, as we know, two kinds of transport in the transmission of a current through a decomposable liquid; one, that I will call *chemical* transport, which is that in virtue of which the acid of the salt of a solution is shown at the positive electrode, and the base at the negative electrode; the other, *mechanical* transport, in virtue of which the liquid itself is carried from the positive to the negative pole, with an energy greater in proportion as it is a less conductor. We have explained in detail the researches that have been

* *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxii. p. 38.
† Idem, t. xxxiii. p. 14.

made upon this latter point, and in particular those of M. Wiedemann.* Since then MM. Van-Breda and Logemann, and M. Wiedemann himself, have submitted the question to fresh experiments. MM. Van-Breda and Logemann† have in vain endeavoured to discover a mechanical movement of the molecules of a liquid traversed by a current, when there is no diaphragm; and notwithstanding their experiments were conducted so that, if this movement had existed, it must have manifested itself. Thus, they were not able to prove any difference in the level of the water, traversed by a powerful electric current, at the positive and the negative pole; thus again, they did not perceive any acceleration or retardation in the velocity of the escape of the water, placed in a Mariotte vessel, according as the current, which traverses it, was travelling in the direction of the escape or in the contrary direction. The phenomena take place quite differently as soon as there is a porous diaphragm; and yet this diaphragm, rendered movable, is in no way drawn along in the same direction as the liquid, which would be the case if the movement were really the effect of a direct mechanical action that electricity exercises upon the liquid, and which pushes on the liquid molecules through the pores of the diaphragm. Moreover, MM. Van-Breda and Logemann have verified all the laws of the phenomenon, as they had been given by M. Wiedemann, and found them perfectly accurate. They likewise confirmed the result that I had obtained‡; namely, that the quantities of gas developed in the same time in two successive voltameters, one charged with acidulated water, the other with pure water and a diaphragm, are sensibly equal, even while a mechanical transport of the liquid is produced in the latter voltameter, which does not exist in the former.

M. Wiedemann, in his new researches upon this subject§, does not question the results obtained by MM. Van-Breda and Logemann, which he had himself observed; but he does

* Vol II. p. 434. *et seq.*
† *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxiii. p. 5.
‡ Vol. II. p. 441.
§ *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxiii. p. 177.

not the less persist in seeing two distinct phenomena, when a current traverses a decomposable liquid, — electrolytic action and the action of transport. The former always takes place at the same time with the latter, with which it is connected by certain relations. A very great number of experiments, made with the greatest care upon the electrolysis of saline and acid solutions, lead M. Wiedemann to establish the accuracy of the results obtained by Daniell and by M. d'Almeida, which we have made known. These same electrolyses, made with the adjunct of a porous partition, which separates hermetically into two distinct portions the liquid submitted to electrolysis, show that the quantity of the base transported from the positive pole to the negative is greater when a porous partition is interposed than when there is none. This transport is less as soon as solutions of sulphuric or nitric acid are in question, from which the transport takes place from the negative to the positive pole, when the operation takes place without a porous partition. With a porous partition, beside the base, the liquid itself, as we know, is transported to the negative pole, and the volume of the solution is increased there. This transport is even sensible with better conducting liquids, as the saline solutions; but yet it is the more decided in proportion as the resistance of the liquid to electric conductibility is greater.

If the increase of volume is produced solely by the mechanical transport of the unaltered liquid, we see that, for different concentrations, the quantities of liquid transported are nearly in reverse ratio to the quantity of salt dissolved, and contain consequently nearly the same absolute quantity of salt. To sum up, M. Wiedemann has arrived by his researches to believing that, in the phenomena of electrolysis, the current that penetrates into the liquid, is divided into two parts, one of which, the larger, is transmitted through the salt, and the other, much smaller, traverses the water. The purely electrolytic action would consist of this, — that the electricity that comes out by the positive electrode attracts the electro-negative element of the nearest molecule of salt, whilst the electro-positive element (the

metal) remains in its place, and the electro-negative element travels toward the positive electrode. Thus it is that the metal is separated from the oxygen and the acid, and is combined with the electro-negative element of the following molecule, and so on; so that, at the end, it is deposited upon the negative electrode, whilst the oxygen and the acid accumulate at the positive if it is of platinum; but, if it is of copper, for example, when the electrolysis of sulphate of copper is in question, as much copper is dissolved as there is deposited on the negative electrode. We see that this theory is nearly that which we have given of electrolysis; only M. Wiedemann adds to it, by the side of the electrolytic action, a mechanical action, which takes place for the salt, as well as for the water, but which is much more decided for the part of the current that passes by the water, the electrolytic effect of which consequently is very feeble. Experiments have in fact shown that, during the decomposition of a grain of water, there is a transport of about 5000 grains of water through a porous partition, which makes M. Wiedemann suppose that in the greater number of cases the work employed in this latter action is much greater than that which produces decomposition. But it appears to us impossible to compare these two kinds of work, in consequence of the different nature of the two kinds of force necessary for one and for the other, the latter requiring force probably of a much greater intensity than the former. According to M. Wiedemann, it is the viscosity of the liquid, that is opposed to the transport; the electric resistance must, therefore, have a very simple relation with this viscosity, to which it must be proportional, whilst it is less in proportion as the quantity of salt dissolved in the same volume is greater. The degree of viscosity has been determined by the time that a liquid employs for escaping under a constant pressure through a capillary tube; and it has thus been found that it varies for each solution with its degree of concentration.

Notwithstanding the new researches of M. Wiedemann, the accuracy of which leaves nothing to be desired, we will

confess that we could not see in the mechanical transport of liquids under the influence of the electric current a direct effect of this current. In other words, the presence of the porous diaphragm appears to us a necessary condition not only for manifesting, but even for determining the phenomenon. It seems to us to result evidently from the researches of MM. Van-Breda and Logemann that, without the diaphragm, there is no transport; and nothing in Wiedemann's experiments proves that it is otherwise. We should, therefore, be disposed to see, in the phenomenon of transport, a simple phenomenon of endosmose. It is true that in order that endosmose may take place, it is necessary that the liquids, separated by the porous diaphragm, should be heterogeneous; but, is it not very probable that the two surfaces of the electrolytic liquid, that are separated by the diaphragm are not identical, as soon as this liquid transmits an electric current? Now, as endosmose acts by these surfaces, it is sufficient that they be constantly retained in a state of heterogeneity in order that endosmose may take place. In proof of the very special influence of the diaphragm upon the two surfaces of the liquid that are in contact with it, when at least this liquid is traversed by an electric current, we will cite the fact of the considerable elevation of temperature which takes place in the liquid on the two sides of the diaphragm, and which is different on one side from what it is on the other. It would not be impossible that this elevation of temperature, which is greater in proportion as the liquid is a worse conductor, might be very intimately connected with the phenomenon itself of electric endosmose, either as a cause, or at least as due to the same cause.

We should also have to cite some other works recently executed upon electrolysis, such as that of M. Dupré*, who has verified Faraday's laws upon several salts of copper and silver, thus completing the researches of M. Soret and M. Buff†; such, especially, as that of M. Magnus‡, who, as

* *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxv. p. 98.
† Vol. II. p. 388. *et seq.*
‡ *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxii. p. 327.

the result of a very great number of experiments, is led to reject Daniell's theory, which we had admitted*, upon the manner in which electro-chemical decomposition of salts is brought about. He does not think that it is the metal alone which presents itself at the negative electrode, whilst all the other elements of the salt present themselves at the positive; but he admits that it is indeed the base of the salt, that is to say, the oxide itself, that is deposited upon the negative electrode with the hydrogen of the water, whilst the oxygen and the acid are liberated at the positive. With regard to Daniell's objection that there results a double decomposition of the salt by the same force that produces only a simple one in a voltameter, placed in the same circuit, he thinks that it is not necessary, in order to reply to it, to have recourse to the explanation of the English philosopher; but he is much rather led to conclude from his researches that, in order to separate a simple body from a combination, it is always necessary to employ the same force, whether this body be combined with one other simple body only, so as to form a binary compound, or be combined with several other simple bodies, so as to form a saline compound. M. Magnus considers that, by help of this principle, it is not difficult to show that Faraday's laws of electro-chemical equivalents can be applied, not only to binary compounds, but also to saline compounds, and to other inorganic combinations. He supports his opinion upon the study that he has made of the conditions under which the separation takes place of a substance by the current that traverses an electrolyte, in which are found several substances susceptible of being separated; and he finds that their separation depends upon several circumstances, such as the density of the current, the proportions of the different substances in the solution, the nature of the electrodes, and the greater or less facility with which these different substances may be transported from one layer to another, as well as of the obstacles that may be opposed to this transport, by employing porous

* Vol. II. p. 361.

separations, or in any other manner. Without failing to recognise every thing that is plausible in M. Magnus's reasonings, and the attention that must be excited among philosophers by the new facts that he describes, it seems to us that none of these facts are contrary to the theory that we have given of the electrolysis of saline solutions; and we persist in believing that this theory, independently of the advantage that it presents of conforming more naturally to Faraday's law, possesses this also,—that of comprising under the same explanation the decomposition of the salts which, like the salts of copper and silver, present at the negative electrode only the metal itself without hydrogen, and of those which, like the alkaline or earthy salts, present to this electrode the metallic oxide with hydrogen.

If we were not compelled to restrict ourselves, we should dwell for some moments upon some recent researches of M. Clausius, relative to the general study of the transmission of electricity through decomposable liquids. Setting out from the idea, to which he was led by his theories upon heat, that the molecules are constantly in motion, he supposes that in an electrolyte there are, by the side of the compound molecules, a certain number of simple molecules in motion; that an electro-positive molecule, for example, moving in the electrolyte, is able to arrive into such a position that its attraction for the negative of the compound molecule is greater than is that of the electro-positive molecule belonging to the same molecule by the electro-negative that is coupled with it. Decomposition will take place in it, but then an electro-positive molecule will be set at liberty, and will go and play the same part toward another molecule. All these decompositions and recompositions are constantly produced in the body of an electrolyte; and, as they compensate each other, no change is observed. But, if we plunge the two electrodes into an electrolyte, then a direction is given to this movement; and the positive molecules, being set at liberty, are transported in greater quantity toward the negative pole, and reciprocally; by this a liberation or accumulation of the molecules on the two extremities is brought about. Thus,

whilst, in Grotthur's theory, the faculty of producing a decomposition is attributed to electricity, in that of Clausius it is admitted that the decomposition pre-exists, and that electricity only gives to it a determinate direction.

12. — *Researches on the Electro-motive Force.*

In a paragraph, devoted to the measure of the relative electro-motive force of various voltaïc combinations*, we have made known in detail the various processes employed for this determination, and the results obtained by these processes. Since the publication of the Second Volume of this Treatise, fresh researches have been made upon this subject, in particular by M. E. Becquerel †, who has applied himself to an extensive work, comprising the determination both of the electromotive forces arising from the polarization of the electrodes, and of those due to the action of solutions upon each other, as well as to the action of liquids upon the metals, and finally of the electro-motive forces of the different batteries, and in particular of gas batteries. Among the methods that we have pointed out for this class of researches, he has adopted that of Fechner ‡, which consists in introducing into the circuit of the voltaic pairs a resistance, very great in respect to that of these pairs, so that, when they are compared, we may regard their total resistances respectively as equal, and to admit consequently that their electro-motive forces are to each other as the intensity of the currents which they produce. Instead of the galvanometer, the indications of which are not proportional to the intensities, except as far as 20°, M. E. Becquerel has employed the electro-magnetic balance contrived by his father §, which has given to him very accurate results. Without dwelling upon the precautions necessary in the use of this instrument, and pointed out by M. Becquerel, we shall confine ourselves to remarking that the resistances which the current encounters in traversing the wire of the two bobbins is equal to that of a wire 1024600 feet in length, and 0·0393 inch in diameter, which

* Vol. II. p. 783. *et seq.*
† *Annales de Ch. et de Phys* (N. S.), t. xlviii. p. 257.
‡ Vol. II. p. 785. § Vol. I. p. 340., fig. 139.

represents a resistance thirty-three thousand times greater than that of an ordinary Bunsen's pair, or of a Grove's nitric acid pair, and consequently fulfils the desired condition for the employment of Fechner's method; although it nevertheless appears to us that M. Becquerel does not take sufficiently into account the immense difference that exists between the resistance that is presented by such pairs as those of Grove and Bunsen, and pairs of the same dimensions, but charged with pure water, or other liquids that are not very good conductors. Although he has established the relation that exists between the electro-motive force of a bismuth-copper thermo-electric pair, and those of a Bunsen's and of a Daniell's pair,—a relation, which he has found very near to that which M. J. Regnault* had obtained, he has preferred to take for unit of electro-motive force that which results from the action of water acidulated by sulphuric acid (9 water + 1 acid) upon zinc distilled and melted. In this manner his unit was less removed from the values of the electro-motive forces that he was desirous of determining; he was, moreover, able always to reduce his results to the unit deduced from the electro-motive force of a thermo-electric pair.

The determination of the electro-motive force, resulting from the polarization of the electrodes has greatly occupied M. E. Becquerel: we have already dwelt at length upon this subject†, so that we shall not now dwell upon it; the more so as M. E. Becquerel concludes, from a very great number of experiments, that it is not possible to express in a simple manner the electro-motive forces of metals covered with oxygen or hydrogen gas by the electro-chemical way, seeing that the effects vary with the extent of the plate of metal, its nature, and the intensity of the current. The following, however, are the results of experiments made with plates of platinum with a surface of 1·55 square inch, plunged into water, acidulated with sulphuric acid to a tenth, and by operating with a battery of 8 or 10 Bunsen's pairs:

* Vol. II. p. 795.

† Vol. II. 797. *et seq.*

Electro-motive force of platinum covered with hydrogen - - - - - 37·62.
Electro-motive force of platinum covered with oxygen - - - - - 53·56.

This latter electro-motive force would be 9·00 if, instead of plunging the platinum into acidulated water, it is plunged into ordinary nitric acid. These electro-motive forces are expressed in fractions of the unit represented by 100,—a number which indicates the number of milligrammes (0·0154 grain) with which it is necessary to load the electro-magnetic balance in order to produce equilibrium with the force of the current, arising from a pair of platinum and pure zinc in water acidulated with sulphuric acid to one-tenth. Chlorine gives the metals only a very feeble polarization, which is probably due to its great solubility. With regard to gas batteries, M. Becquerel, who has studied them, does not think that they are in the same conditions as the pairs constituted by polarized metal plates; since hydrogen gas alone, in contact with platinum, in presence of acidulated water deprived of air or oxygen, and in which a plate of platinum is plunged, cannot constitute a pair; whilst a plate of platinum, covered electro-chemically with hydrogen, has an electro-motive force proper, even in vacuo; which would seem to indicate that gases, transported by the electro-chemical way in the act of polarization, are in other conditions than those which surround the plates, and which are prepared by the ordinary chemical processes. Might it not be possible that the difference is due to the fact that, in the case of the gas-battery, the hydrogen is in contact with the liquid, rather than with the platinum plate, whilst in the latter it is the metal plate, that is covered with a thin film of hydrogen, which in this state is capable of decomposing water without the assistance of the dissolved oxygen? It would therefore seem that the difficulty, raised by M. E. Becquerel, is not so great as he presumes.

The study that he has made of the electro-motive forces that result from the action of solutions upon each other, when separating them by a porous diaphragm, shows that, in voltaic pairs with two liquids, this action has a much

greater influence than might be supposed, over the production of the electric current. Thus, for example, the mutual action of nitric acid and persulphuret of potassium gives rise to an electro-motive force of 72·50, the platinum plate, placed in the nitric acid taking positive electricity, and that which is in the persulphuret, negative. Besides, the electro-motive forces that result from the action of two solutions upon each other, change with the degree of concentration and the temperature of the liquids, and constitute the eminently variable part of the electro-motive force of the pairs, especially of those with two liquids, called constant current pairs.

Of all the determinations of electro-motive forces, the most important is undoubtedly that of the electro-motive forces due to the action of liquids upon metals. In order to obtain it, it is necessary to employ two metal plates, one of which is of a metal, such as platinum or gold, that is not attackable, and which has a surface sufficiently large for its polarization not to be sensible, which is obtained by operating rapidly. The liquid, in which the two plates are plunged, naturally exercises a great influence over the electro-motive force of the same metal. With chlorine-water, not only have the oxidizable metals a very great electro-motive force, but also copper, silver, and antimony, which are sharply attacked, give an energetic current; gold itself gives one. By employing water acidulated with sulphuric acid, we see that the degree of acidity has little influence over the electro-motive force, except for silver. With a solution of caustic potash, the order of the metals, in respect to electro-motive forces, is found changed; this is what Mr. Faraday and I* had long ago remarked. There are two metals, which, with all the liquids employed except sulphuret of potassium, preserve the same relations of electro-motive force; these are zinc and lead. M. E. Becquerel insists upon the changes in the direction of the current, which result from a pair, composed of the two same metals, from its immersion into two different liquids; this is a point that I have already discussed in

* Vol. II. p. 667. *et seq.*

detail; I shall therefore not return to it. He has been also occupied with the electro-motive force of amalgams, which he sometimes finds, as with zinc, more powerful, sometimes, as with cadmium, more feeble than that of the pure metal. Finally, among all pairs, he is led to recognise that the one whose electro-motive force is the greatest is the pair that is formed of the amalgam of potassium and of a layer of peroxide of lead deposited voltaically upon a plate of platinum. Its electro-motive force is expressed by the number 236·78, still calling 100 that of pure zinc with water acidulated with sulphuric acid to the tenth. It is double that of an ordinary Bunsen's pair.

After potassium, the metal that has given M. Becquerel the greatest electro-motive force in a solution of caustic potash is aluminium. In water acidulated with sulphuric acid, its electro-motive force is inferior to that of zinc, cadmium, lead, tin, and iron, but superior to that of nickel, cobalt, bismuth, antimony, copper, and silver. Mr. Wheatstone had obtained results almost similar to those of M. E. Becquerel in regard to aluminium*; and M. Hulot has endeavoured, with success, to employ it as the electro-negative element of a pair in which amalgamated zinc is the electro-positive element, and the liquid, water acidulated with sulphuric acid to one-twentieth.† During the first hours, the current of this pair was found to be as strong as that of a pair of platinum-zinc plunged into the same liquid. It is merely necessary when the force diminishes to plunge the aluminium for a moment into nitric acid, and then to wash it, in order to restore to it its electro-negative properties. M. Buff has noticed that aluminium becomes positive in nitric acid, so that a pair may be formed of it with aluminium plunged, on the one hand, in nitric acid, and on the other, in diluted sulphuric acid: the electro-motive force of this pair is 0·63 of that of a Bunsen's pair. If, instead of aluminium, another metal is plunged into the diluted sulphuric acid, it is found to be electro-positive in respect to aluminium, that is in nitric

* *Arch. des. Sc. Phys.* (*Bibl. Univ.*), t. xxxix. p. 350.
† *Comptes Rendus de l'Acad. des Sc.*, t. xl. p. 1148.

acid. Platinum is the only metal that, under the same conditions, is electro-negative.*

In one part of his work, M. Becquerel was occupied with the determination of the electro-motive force of the different kinds of batteries; the results that he obtains show that the action of the solutions enters, as we have said, as a notable part in the effect of each pair. By calling the electro-motive force of a Grove's pair (amalgamated zinc and acidulated water, platinum, and nitric acid) 100, he found 57·67 for the expression of that of a Daniell's pair (amalgamated zinc and acidulated water, copper, and sulphate of copper). By substituting salt water for the water acidulated by sulphuric acid in this latter pair, he found that its electro-motive force increases and reaches to 63·13. M. E. Becquerel obtained 32·5 for that of M. Doat's pair, in which mercury is employed for the attackable metal, and iodide of potassium for the active liquid†: this result agrees with that of M. J. Regnault, who found 32·9 in place of 32·5, by an entirely different method,—his method of opposition.‡ He has extended his researches to pairs in which he has substituted bromide and chloride of potassium for iodide of potassium, and zinc and the amalgams of sodium and potassium for mercury. The electro-motive force is with zinc more than double, and with the two amalgams nearly quadruple what it is with mercury. It is for each metal more powerful with the bromide and the chloride than with the iodide, in the ratio of about 100 to 160 for the bromide, and of 100 to 180 for the chloride. In M. Doat's pair, and those which are analogous to it, the liquid iodide of potassium, with which the mercury or other attackable metal is in contact, is placed in a porous trough; the latter is itself plunged in another solution of iodide of potassium, which contains dissolved

* M. Buff has likewise determined the electric conductibility of aluminium. He has found, by calling 100 the resistance of pure silver, that that of aluminium, almost pure, soft, and flexible, was 199·63; and that that of the aluminium of commerce was 210·92; that of pure and soft copper was 106·46; and that of soft and slightly elastic iron, 676·71. *Archives des Science Phys.* (*Bibl. Univ.*), t. xxxvi. p. 57.

† *Comptes Rendus de l'Acad. des Sc.*, t. xlii. p. 355.

‡ *Ibid.*, t. xliii. p. 47.; and Vol. II. p. 793.

iodide, which in its solid state, being placed in excess, serves to maintain the constancy: it is carbon that is employed as the negative element. A battery composed of M. Doat's pairs has no need of any other care than that which consists in drawing off, by aid of a glass siphon, the liquid saturated with iodide of mercury,—an iodide, which is easily re-vivified by heat, in order to recover the original elements. However, notwithstanding the facility that is experienced in regenerating the products formed by chemical action, the trouble that it occasions, the high price of the materials that are employed, and especially its feeble electro-motive force, do not permit of M. Doat's battery becoming much used.

13.—*Transformation of Electric Heat into Mechanical Work.*

We have set forth the various researches that have been made in order to establish a relation between the heat produced directly by a certain chemical action, and that which arises from the electricity that is generated by this same chemical action.* We are aware that M. Favre has demonstrated, by experiments well pursued and conclusive, the principle which I was the first to put forth, as the result of a single experiment, namely, that, in a circuit, the sum of the heats liberated, both in the battery as well as in the conductor by which the poles of the battery are united, is constant for a same quantity of chemical action. The object of recent researches has been to study the transformation of the heat, that results from this chemical action into mechanical work, by the intervention of electricity. M. Favre† has just demonstrated experimentally that the mechanical work produced by a current always incurs an expense of heat, borrowed from the total heat, that is liberated by the chemical actions of the battery. The following is his mode of operating:—A first calorimeter contains the voltaic battery, the five pairs formed of amalgamated zinc and platinized platinum; a second calorimeter receives an electro-motor, constructed by M. Froment for this special purpose. In order

* Vol. II. p. 867. *et seq.*

† *Comptes Rendus de l'Acad. des Sc.*, t. xlv. p. 56.

to render the helices of the electro-magnets capable of cooling more easily, they are composed of a series of conducting discs, separated by very thin insulating discs; these discs, which present at the exterior their metallic sections, and which are merely separated by the thin sections of the insulating discs, communicating together so as to establish a continuous scroll from one extremity to the other of the bobbins. They are insulated from the soft iron cylinders which they envelope, as well as they are from each other. The arbor of the electro-motor comes out of the calorimeter, and communicates by an endless strap with an arbor of conical spindles, carrying a pulley upon which a cord is wound, which raises a weight. M. Favre first made the battery act alone in its calorimeter, all the work produced by the chemical action being then accomplished in the battery itself; the heat liberated gave him the measure of it; he found 18,682 calories per gramme (15·432 grs.) of hydrogen liberated. On then making the current pass through the thick wires that are to make the battery communicate with the electro-motor, he satisfied himself that their resistance may be neglected; then, on making the current pass into the electro-motor, but without setting it into motion, he found, for the heat developed in the battery calorimeter, 16,448; and for the electro-motor calorimeter, 2219, which gives a sum of 18,667, differing from the primitive work, still considered as the motor work, by only 15 units —a difference inseparable from experiments of this kind. The electro-motor was then set in motion, but without making it raise any weight; this series of experiments gave for the sum of the work, resulting in both calorimeters, the number 18,657. Thus the principle of the constancy of the heat developed in a circuit may be considered as extended to that which is developed under exterior actions.

When the electro-motor has caused a weight to rise, producing a work of 131 kilogrammètres (1 lb. raised 7·234 feet high), the sum of the two quantities of heat, indicated by the two calorimeters, was 308 units lower than the original sum; so that we must consider these 308 units as equivalent to 131 kilogrammètres of motor work.

The question discussed by M. Favre has also engaged the attention of M. Soret, who has regarded it under a slightly different relation.* He first occupied himself with the variations of intensity, that the current undergoes when it produces a mechanical work. We have already given M. Jacobi's† researches in this respect. We shall content ourselves, as far as concerns those of M. Soret, with remarking that he has been able to sum up his results by saying,—that, when a continued electric current tends to determine a relative movement of two pieces of an apparatus, if the two pieces are displaced by yielding to this action, that is to say, if there is produced a positive mechanical work, a diminution of the intensity of the current is observed, whilst this movement is being accomplished; and inversely, when we compel these two pieces to assume a movement opposed to that which the electric forces tend to give to them,—that is to say, if the mechanical work is negative,—an increase of the intensity of the current is observed. M. Soret has remarked that, when the machine moved by electricity is compelled to assume a reverse movement, we arrive at results which do not seem to agree with the theory of electro-motors, in which we are only occupied with the case in which the motion of the machine is accomplished in the natural direction. This difference arises principally from the fact that the current is not continuous, and from the circumstance that there result from it the production of induction currents which, being directed, some in a direction contrary to that of the primitive current, and others in the same direction, do not compensate each other; seeing that the latter are unable to propagate themselves, because the circuit is interrupted at the moment when they are developed. Moreover, different experiments show that the variation of intensity, resulting from the displacement of the pieces that are attracted, is much more feeble than that which arises from the magnetic and electric inertia, when discontinuous currents are employed.

* *Comptes Rendus de l'Acad. des Sc.*, t. xlv. p. 301. and 308.; and *Arch. des Sc. Phys.* (*Bibl. Univ.*), t. xxxvi. p. 38.

† Vol. III. p. 343.

Coming to the question itself of the relation that exists between the heat liberated by the current and the exterior action that it exercises, M. Soret has endeavoured to account for the manner in which the transformation of electric heat into motor work takes place, and to determine the portion of the circuit in which it takes place. He has been induced to presume that it was produced at the place itself where the mechanical work is developed. On taking two helices, perfectly similar and forming part of a same circuit, each placed in a calorimeter, M. Soret thought that, by making one alone of them produce any work, he might perhaps find a difference in the temperatures indicated by the calorimeters. Without entering into the detail of these experiments, which were made by taking the greatest precautions in order to avoid every cause of error, we shall confine ourselves to saying that he introduced into one of the helices a cylinder of soft iron, which the establishment and interruption of the current magnetized and demagnetized; and, according to a first series of experiments made in this manner, one of the helices was made to produce a mechanical work, which gave a backward and forward motion to the soft iron cylinder. The substance of the two series of experiments has demonstrated that the relation of the thermic effects of the two helices did not undergo any regular variation, which might be attributed to the transformation into exterior work of a certain quantity of heat; but we cannot yet conclude that there is no general calorific weakening in the whole sum of the circuit, including therein the acting part. M. Soret would be disposed to believe that, when a current exerts an exterior action, things take place as if we increased the electric resistance of the part of the circuit that acts by induction, which brings about a diminution in the quantity of zinc dissolved, and consequently in the internal heat of the battery; with this difference, that the increase of the mechanical effect which should be produced where the resistance would have received an increase, instead of being carried to the inducing part of the circuit, would be carried upon the induced body.

M. Leroux, in a work upon electro-magnetic and magneto-

electric machines*, has just occupied himself with the same questions that have been the subject of M. Soret's researches, and he has arrived, at the same time as the latter had done, at a similar idea, namely, — that the movement of a part of a circuit (movement necessarily accompanied by a mechanical work), in consequence of the discontinuity of the current, gives rise to a special resistance, which he calls *dynamic resistance*. The intensity of the current, that is to say, the quantity of work put into play during the unit of time, is always in the inverse ratio, all things being equal in other respects to the sum of the dynamic or static resistances. The work put into play, whether this work be exterior, as in magneto-electric machines, or interior, as in the apparatus into which the elements of the battery enter, is divided among the various parts of the circuit (each taken as a whole, that is to say, with the neighbouring bodies) proportionately to the dynamic and static resistances of these parts. We must not lose sight of the circumstance that the sparks and magnetizations absorb a certain portion of the work. This explains why, if we compare the heat produced in the total circuit with the mechanical work, we find a number a little too high for expressing the mechanical equivalent of the heat. It results from this that, in machines moved by electricity, in which we desire to cause the electricity to render the greatest work possible, it is necessary to avoid too frequent changes of direction and the production of sparks.

We may also add to the researches that we have just enumerated those very recent ones of M. Quintus Icilius† upon the determination of the work producing the unit of heat by means of the electric current. In designating by I the intensity of an electric current supposed constant, by V the voltaic resistance of a wire traversed by this current, by U the heat that is developed in it during the unit of time, and by A a constant, we know that we have $U = A\,I\,I\,V$, a formula in which $I\,I\,V$ is nothing else than the work executed by the electricity moved in overcoming the resistance of the wire.

* *Comptes Rendus de l'Acad. des Sc.*, t. xlv. p. 414.
† *Ibid.*, p. 420.

In consequence, we may express it by a number, the unit of which is the unit of work. We arrive at this by adopting M. Weber's absolute measures, in order to measure the electric quantities. In order to employ these measures, it is necessary to fix the unit of distance, the millimètre (0·039 in.); the unit of time, the second; the unit of mass, the milligramme (0·0154 gr.) This being laid down, the unit of work will be the work that it will be necessary to employ in order to move a mass = 1 milligramme, along a road = 1 millimètre, the mass not opposing any other resistance than that of its proper inertia. It follows from this that we obtain the heat that is excited by this unit of work, when we determine the numerical value of the constant A, designating by unit of heat the quantity of heat that is required for increasing the temperature of a milligramme of water one centigrade degree (1·8° Fahr.). Without dwelling upon the very carefully executed experiments of M. Quintus Icilius, in order to obtain U by means of a calorimeter, and to determine I and V by the processes pointed out by M. Weber, we will content ourselves with saying that, by taking the mean of fifty-eight experiments made in three series, each series presenting slightly different conditions, he succeeded in finding 311·7 kilogrammètres for the quantity of work that is produced by the unit of heat,—a number which does not exceed the limits, that include the numbers found for this constant by philosophers according to entirely different methods.

M. Clausius and M. Soret himself* have again been discussing the question of the conversion of the heat of the electric current into exterior motor work. Their ideas appear to us to be in very close relation with those of MM. Joulé and Scoresby, which we have made known in our paragraph relative to electro-motors.†

* *Arch. des. Sc. Phys. et Nat.*, t. xxxvi. p. 119. and 123.
† Vol. III. p. 344.

14. — *Researches relative to Electric Fishes.*

Notwithstanding the details into which we have entered upon electric fishes*, we think it interesting for our readers to make known to them the recent researches of M. Kolliker upon the termination of the nerves in the electric organ of the torpedo,—a termination which physiologists, who have made use chiefly of preparations preserved in reagents, have not been able correctly to perceive. M. Kolliker, having studied at Nice, in the autumn of 1856, the electric organ of fishes quite fresh, has succeeded in finding the true termination of the nerves in question.† After having formed the pale ramifications, known and very well figured by M. Wagner, and hitherto regarded as the veritable terminations, the nerves are divided into pale and very slender branches, which, anasmotosing in all directions, form a very elegant and delicate *nervous network*. The network, whose constituent fibriles do not measure more than from 0·00005445 in. to 0·0000726 in., and the meshes of which present the same size, forms of itself a special nervous membrane of from 0·0000726 in. to 0·00009075 in. in thickness, which is extended in the whole space of an electric partition, being applied everywhere in a homogeneous manner, containing nuclei, which serve to support it. Each partition of the electric organ, which is separated from the neighbouring ones by a small space, containing a clear fluid, is formed of six layers: in the middle are situated the great nervous ramifications and the blood vessels, supported by a homogeneous conjunctive tissue; then come on both sides the delicate membranes, formed by the nervous network described, which are finally covered by homogeneous membranes with nuclei, which bear no traces of the epithelium on the side of the space containing the fluid. These nervous networks are extremely delicate, which is the cause of their being destroyed by almost all the reagents that are employed in such observa-

* Vol. III. p. 62.
† *Comptes Rendus de l'Acad. des Sc.*, t. xliii. p. 792.

tions as these, and of their not being seen except on specimens taken from the living animals, or from those which are quite fresh. M. Kolliker remarks that the density and richness of the terminal nervous expansion are not insignificant for the explanation of the very special functions of the electric organ. It in fact appears to us that M. Kolliker's observations are of a nature to give a support to the explanation that we have given of the action of the electric organ*, and upon the principal part which the terminations of the nerves that abut upon it have in this action.

We will take advantage of the opportunity which leads us to direct our attention afresh to the electricity of torpedos, in order to repair an omission that we had made in not mentioning the remarkable work that had been accomplished on this subject in 1836, by Professor Colladon.† Without dwelling upon the experiments by which M. Colladon had proved the electric state of the different points of the body of the torpedo, we will insist upon an important fact which he had observed at the same time as M. Matteucci on his part observed it, and which had guided him to a theory of these phenomena, which, even though it might not now be admitted, as it presented itself, rested upon the same incontestable principle of the bipolarity of the particles. Having placed the two terminal platinum points of a galvanometer in contact respectively with the lower and upper parts of the body of a torpedo, exhausted by the effect of several excitations, M. Colladon wished to know whether it would still give shocks when it was deeply wounded. With this view he first made some deep incisions in the fleshy part of the body of the animal, without obtaining any sensible deviation; then, thrusting the point of a pen-knife into the cerebellum of the torpedo thus mutilated, he saw the galvanometer needle fly completely round; he obtained the same result by acting, in like manner with an ivory point, upon another torpedo. This important experiment plainly proved

* Vol. III. p. 72.

† *Institut* of Oct. 28. 1836, p. 150.; and *Comptes Rendus de l'Acad. des Sc.*, t. iii. p. 490.

the predominant influence of the nervous system in the production of the electricity of the torpedo, — an influence which ulterior researches have rendered still more evident, by demonstrating that it is the source itself of this electricity.

15. — *New Researches upon the Variation of the Magnetic Elements of the Terrestrial Globe.*

We have made known in an abridged manner* the numerous works that have been done upon this interesting subject, and in particular those which have been executed under the direction of Major-Gen. Sabine, in the stations selected upon the points of the terrestrial globe most distant from each other; in particular at Toronto, St. Helena, Cape of Good Hope and Hobart Town; we have likewise set forth the researches of Father Secchi, who, taking advantage of all these observations, has endeavoured, not without success, to connect the variations of the magnetic elements of the globe with the position of the sun in respect to the earth.†

In order to complete, as much as is possible, this part of my work, I have a few words to add, both upon a new work of Father Secchi, as well as upon some new and very interesting approximations pointed out by Major-Gen. Sabine‡, M. Wolf, and M. Lamont, between the variations of the magnetic elements and certain astronomical phenomena.

Father Secchi had established the laws of the diurnal variations of declination, then those of the diurnal variations of the inclination, which he had deduced from the laws of the diurnal variations of the horizontal and vertical component of intensity.§ But he had found that the laws of the variations of the total intensity are less easy to recognize, for want of

* Vol. III. p. 222.

† Ibid. p. 274.

‡ General Sabine has just published in the *Phil. Mag.*, October, 1857, p. 297., a very interesting summary of all the results obtained by the observations made in the magnetic observatories under his direction.

§ *Vide*, for the statement of these laws, Vol. III. p. 274. *et seq.*; and *Ann. de Ch. et de Phys.* (N. S.), t. xliv. p. 246.

sufficient observations, especially in the neighbourhood of the equator. He had, however, recognized in these variations two diurnal maxima and minima; and that in winter the total intensity would seem greater than in summer. To sum up: he arrived at the conclusion that all the magnetic variations depend upon the sun, which, in the mean latitudes, determine a period of twelve hours, which is combined with a period of twenty-four hours, resulting from the difference, that is determined between the amplitude of the nocturnal and that of the diurnal oscillation, by the interposition of the earth between the sun and the magnetized needle during the nocturnal period.*

In a recent work†, Father Secchi has been occupied no longer with the regular variations, but with the extraordinary disturbances, making use of the numerous observations of General Sabine, and in particular of those made at Toronto; and he has succeeded in finding laws to which they are subject. The first of these laws, when the diurnal period is in question, is, — *That the disturbances follow the local time; and that they affect simultaneously all the magnetic elements.* The second is, — *That the disturbing curve is the ordinary curve, only displaced exteriorly by a certain quantity.* Father Secchi has traced the ordinary curve by drawing for each hour of the day upon the axis of the abscissæ a length equal to the variation of the declination at the same hour; then, it is by increasing or diminishing each abscissa and each ordinate, corresponding to each hour, by the mean effect due to the disturbance, that he obtained the disturbed curve, the contour of which is nearly similar to that of the former, with the difference only which results from a total displacement. The comparison of the two curves leads to a third law, namely, — *That, by the effect of the disturbances, the curve always tends to become more symmetrical and equal in its two lobes.* This singular and unexpected result has been verified by Father Secchi in different manners; and he has deduced from it the conclusion, — *That the periods are con-*

* Vol. III. p. 279.

† *Arch. des Sc. Phys. et Nat.* (*Bibl. Univ.*), t. xxxv. p. 161.

nected by a very simple law, having for a basis a variation in the force, which produces the periodical variations, and which is manifested in the variation of the divers elements, according to the geometrical law of the decomposition of forces.

After the diurnal period comes the annual period, which may be summed up in a very simple law; it is, *That the disturbances are at a maximum at the equinoxes, and at a minimum at the solstices.* M. Wolf has thought he could recognize an analogous relation for the solar spots, the minima of which correspond to the two periods, when the earth is passing through the plane, containing the axis of the sun and a parallel to the axis of the earth, that is to say, at the epochs of the solstices; and the two maxima at the two epochs in which the earth is removed the farthest possible from this plane, that is to say, at the epochs of the equinoxes. He has insisted upon the correspondence that exists between this annual period of the solar spots and that of the variations of terrestrial magnetism, deduced from the combination of the variations in declination observed in the northern hemisphere with those of the southern hemisphere, a combination made in order to eliminate the influence of the declination of the sun.

But it is in the decennial period that a remarkable correspondence is chiefly found between the variations of the solar spots and a change of the magnetic variations that we have already remarked.* Announced, in 1843, by M. Schwabe, as far as the spots of the sun are concerned, and subsequently, by M. Lamont, for the magnetic declination, this decennial period was established in 1852 for both the phenomena, first by Major-Gen. Sabine, and a few months afterward by M. Wolf and M. Gautier, who had no knowledge of the remark of Major-Gen. Sabine. Since that time this latter observer and M. Hansteen have satisfied themselves that this period extended to the variations of all the magnetic elements, and even to those of the auroræ boreales. M. Wolf, who has made considerable researches into the ancient observations of the spots of the sun, arrived at the value of

* Vol. III. p. 280.

$11\frac{1}{9}$ years for the mean duration of this period,—a value which appears to him confirmed by the special study that he has made on the magnetic variations observed since the termination of the last century. The only question here is of a mean quantity; for M. Wolf has proved effects of disturbance, due to causes as yet unknown, which sometimes alter in certain years the return of a maximum or minimum of spots, and which are analogous to those that are observed in the periods of fixed stars of variable brilliancy. Several astronomers, as Sir John Herschel, Mr. Carrington, and M. Wolf, have already remarked, that this helio-magnetic period of $11\frac{1}{9}$ years very much approximates to that of the revolution of the planet Jupiter around the sun, which is about 11 years and 10 months. M. Wolf has moreover put forth the supposition that it corresponds to the *tropical* revolution of Jupiter, that is to say, relative to its equinoctial points, rather than to its *sidereal* revolution: the former of these revolutions must be a little smaller than the latter, especially on account of the flattening of Jupiter, which is twenty times greater than that of the earth. In fine, M. Wolf has very recently announced that, having sought as to whether the planet Venus might not also have some influence over the spots of the sun, he has found a very marked maximum, which seemed to him to correspond to the epoch of the perihelion of Venus: further observations however are required, before any sound opinion can be formed. We have already remarked the magnetic influence of the moon*, which has been rendered evident with rare skill by Major-Gen. Sabine, for Toronto, St. Helena, and Hobart Town. All the magnetic elements are influenced by the moon; and there are found for the lunar variations laws similar to those which had been recognized for the solar variations; but these variations are much more feeble.

We shall not follow Father Secchi in the study that he has made of the secular variations, with a view also of demonstrating, in their progress, the influence of the sun. We shall confine ourselves to adding that M. Lamont, on his part, has found that the secular variation of the declination

* Vol. III. p. 259. *et seq.*

is tolerably regular, and may be regarded as an oscillation of a long period; only a very remarkable retardation took place between 1855 and 1856. The same observer communicates to us some further interesting results, namely, that the horizontal intensity increases by $\frac{1}{50}$th, and the total intensity diminishes by $\frac{1}{450}$th per annum, but in an irregular manner; it is probably this irregular movement which produces the small irregularities of the secular variation of declination. M. Lamont, as the result of numerous calculations for discovering the laws of the diurnal movement of the three elements, has succeeded in finding a great regularity in the co-efficients of the different months, but without the number following any simple laws. He thinks that he has demonstrated that the ideas of Mr. Lloyd, upon the connection between the temperature of the air and the magnetic movements, have no foundation; neither does he consider that he can adopt the conclusions that Major-Gen. Sabine has deduced from the observations of St. Helena, in respect to the influence of the sun, and of the opposite inflection of the curves, according as the declination of the sun is austral or boreal.

16.—*M. Wartmann's Process for establishing an Immediate Correspondence between any two of the Stations situated upon a same Telegraphic Line.*

We have described (pp. 406, &c.) the means employed for establishing a direct communication between two distant telegraphic stations. The plan most in use consists in requiring of all the intermediate stations that they break their connection with the earth; but, besides this mode requiring a tolerably long time, it presents the inconvenience that the despatch is reproduced by the relay in each of the stations. M. Wartmann made known in 1853* a process which enables him to obtain with a single telegraphic wire all the advantages that would be obtained by having special wires for uniting the stations with each other. Each station must be furnished with a relay, composed of two electro-

* *Archives des Sc. Phys. et Nat.* (*Bibl. Univ*), t. xxiii. p. 5.

magnets, fixed on the two sides of a magnetized armature, arranged see-saw fashion, which is repelled against a stop by an antagonistic spring. Beneath that extremity of the balanced bar which is not connected with the antagonistic spring, is fixed a spring-plate so arranged as to be wound up by this extremity; this plate generally rests against a screw connected metallically with the earth, whilst the plate itself communicates with the wires of the two electro-magnets, which are themselves in the circuit of the line-wire.

Suppose some three stations A, B and C: if we telegraph between A and B, we employ a current of an intensity sufficient to overcome the resistance of the circuit to be traversed; but this intensity is not sufficient to cause M. Wartmann's relay-plate, which is placed in the circuit at B, to act, on account of the resistance of the spring, by which it is retained, which has been calculated for this purpose. But, if we desire to telegraph from A to C, we employ a more powerful current; and this increase must be such, that it triumphs over the resistance of the spring of the magnetized plate, which, being attracted by the electro-magnet, causes all communication of the relay with the earth to cease; at the same time, this movement establishes direct communication between A and C, without the intervention of any person in attendance being necessary. If the station C possesses an apparatus analogous to that of the station B, we shall be able, by still further increasing the strength of the current, to extend direct communication as far as a station D, and so on.

In order that all these communications may be conveniently established, it is necessary to have several accessory arrangements; the most important is to be able by a simple movement to introduce into the circuit the number of pairs necessary for causing the telegraph apparatus to act by direct communication from such or such station; M. Wartmann obtains this by means of an apparatus of his invention, which he has called a *regulator*. To this apparatus is added an *indicating* apparatus, intended to indicate whether the desired station has been attained, and consequently whether the

current sent forward has an intensity sufficient to cause all the apparatus to act that must close the circuit at each intermediate station. The persistence of the magnetism remaining in the electro-magnets, causes the circuit to remain closed, notwithstanding the small interruptions that are required for the transmission of the telegraphic signals; and, when we desire instantaneously to obtain the rupture of the circuit, we have merely to send into it an inverse current of short duration,—a current which, by reversing the poles of the electro-magnets, causes the magnetized armatures to be detached, which an immediate repulsion brings back again to the stops in each apparatus.

NOTES

RELATIVE TO

MATHEMATICAL DEVELOPMENTS

OF

CERTAIN PARTICULAR POINTS.*

NOTE A. (P. 209.)

Note relative to the absolute Measure of the Intensity of Terrestrial Magnetism.

We give in this note the development of Gauss's method for measuring the absolute intensity of Terrestrial Magnetism. (*Annales de Chim. et de Phys.* t. lvii. p. 5.) It is an interesting example of Mathematical Physics, as much by the generality with which the illustrious geometrician has treated the question, as by the practical results to which he has been led.

In order to comprehend what is about to follow, it is necessary for a moment to return to the fundamental principles of the theory of Magnetism. A magnetic body must be considered as an assemblage of particles, each of which contains equal quantities of the two fluids; and it is the separation to a greater or less distance, or in greater or less quantity, of these two portions of fluid which constitutes the free magnetism of the particle. The attraction, that takes place between two given quantities of

* These notes have been drawn up by M. Lucian de la Rive.

fluids of contrary names, each supposed to be concentrated in a point, is equal to the repulsion produced from quantities respectively equal of fluids of the same name, acting at the same distance. By taking as unity the quantity of fluid which, acting upon a quantity equal to itself and at the unit of distance, produces the unit of accelerative force, the action of a quantity m of boreal fluid upon a quantity m' of the same fluid at the distance r, will be expressed by $\frac{m\,m'}{r^2}$ (by admitting the law of the inverse ratio of the square of the distance); and the formula will be applicable to all cases, if we agree to give the negative sign to the austral fluid, and to understand by an attraction a negative force.

Let us conceive a magnetic body of any form, reduced to three axes of rectangular co-ordinates. Let dm be an element of free magnetism, positive or negative, in a point x, y, z; $x\,dm$ is what may be called the moment of this element, in respect to the base called x upon a plane of $z\,y$; let us make the sum of the products analogous in all the extent of the body, and let us place

$$\int x\,dm = \mathrm{X}\,;\quad \int y\,dm = \mathrm{Y}\,;\quad \int z\,dm = \mathrm{Z}.$$

The value of the magnetic moment of the body, in respect to an axis, does not depend upon the origin of the co-ordinates; in fact we have

$$\int (x-a)\,dm = \int x\,dm - a\int dm.$$

And, as by hypothesis, $\int dm = 0$, we have:

$$\int (x-a)\,dm = \int x\,dm.$$

Expressing the magnetic moment of the body, in respect to an axis, making with the axes of the co-ordinates the angles A, B, C. Let v be this moment.

$$\mathrm{v} = \int (x\cos.\,\mathrm{A} + y\cos.\,\mathrm{B} + z\cos.\,\mathrm{C})\,dm = \mathrm{X}\cos.\,\mathrm{A} + \mathrm{Y}\cos.\,\mathrm{B} + \mathrm{Z}\cos.\,\mathrm{C}.$$

Let us consider in particular the axis, which we call the principal axis, for which we have

$$\cos.\,\mathrm{A} = \frac{\mathrm{X}}{\sqrt{\mathrm{X}^2+\mathrm{Y}^2+\mathrm{Z}^2}};\quad \cos.\,\mathrm{B} = \frac{\mathrm{Y}}{\sqrt{\mathrm{X}^2+\mathrm{Y}^2+\mathrm{Z}^2}};\quad \cos.\,\mathrm{C} = \frac{\mathrm{Z}}{\sqrt{\mathrm{X}^2+\mathrm{Y}^2+\mathrm{Z}^2}}.$$

The value that v will assume will be

$$M = \sqrt{X^2+Y^2+Z^2};$$

and the general expression of v may be put under the form

$$v = \sqrt{X^2+Y^2+Z^2}\left\{\frac{X}{\sqrt{X^2+Y^2+Z^2}}\cos.\,A+\frac{Y}{\sqrt{X^2+Y^2+Z^2}}\cos.\,B+\frac{Z}{\sqrt{X^2+Y^2+Z^2}}\cos.\,C\right\} = M\cos.\,w;$$

indicating by w, the angle that is made by the axis by which the magnetic moment is v with the principal axis. Also, we obtain the magnetic moment of the body in respect to any axis whatever, by multiplying the moment M by the co-sines of the angle that is made by this axis with the axis whose direction has been established by the above equations; we hence conclude that M is the maximum magnetic moment; and that every magnetic moment relative to an axis perpendicular to the principal axis, is null.

In order to explain the action of terrestrial magnetism upon a magnetised needle, we admit that a constant force of intensity and direction (for a constant value of time) comes and acts upon each molecule of free magnetism. By taking as a unit the analogous force which, by acting upon the unit of magnetism, produces the unit of force, and designating by P the terrestrial force, P $d\,m$ is the elementary action exercised, according to a determinate direction and in a manner depending upon the sign of $d\,m$. By counting up all these parallel forces, we shall have for the sum of the moments, according to the co-ordinate axes,

$$\int \mathrm{P}\,x\,d\,m,\quad \int \mathrm{P}\,y\,d\,m,\quad \int \mathrm{P}\,z\,d\,m,$$

or,

$$\mathrm{P}\int x\,d\,m,\quad \mathrm{P}\int y\,d\,m,\quad \mathrm{P}\int z\,d\,m;$$

and, according to the results previously obtained, we see that the resultant of all these actions is a couple, of which the two forces have their points of application upon a right line parallel to the principal axis; and that the sum of the moments of these forces, in respect to this axis, is MP.

This principal axis is therefore the *magnetic axis* of the body; since the latter may be in equilibrio under the action of terrestrial magnetism, and will place itself in such a manner that this axis will coincide with the direction of the force.

We are now about to see how we may measure this force, P; or rather, which is more convenient, its horizontal component, T,

Let us suppose a magnetized needle, whose magnetic axis is horizontal, and which is movable around a vertical axis, conditions which will be fulfilled by suspending it to a thread by the point, where its centre of gravity is found to be transported by the action of the vertical component of the terrestrial force; let us remove it from the position of equilibrium; in order to return to it, it will make a series of oscillations. When a compound pendulum oscillates under the action of gravity, the formula that gives the time of an oscillation of an amplitude that is infinitely small is

$$t = \pi \sqrt{\frac{\Sigma m r^2}{p l}};$$

in which $\Sigma m r^2$ is the moment of the inertia of the pendulum in respect to the axis of oscillation, and $p l$ is the moment of maximum rotation of gravity. This formula is evidently applicable to the case with which we are occupied; and we have merely to substitute in it for the moment of maximum rotation of gravity, that of the horizontal component of the terrestrial force acting upon the needle. Now this action is that of a couple whose static moment in respect to the magnetic axis is M T; the moment of maximum rotation then is also M T; and we shall thus have

$$t = \pi \sqrt{\frac{K}{MT}};$$

in which K is the moment of inertia of the needle in respect to the axis to which it is suspended. We shall deduce from this

$$MT = \frac{\pi^2 K}{t^2}.$$

We therefore thus obtain the product of the magnetic moment of the needle by the horizontal component of the terrestrial force; this product is a moment of rotation, that is to say, a force multiplied by one arm of the lever; and the formula supposes that the units chosen for the lengths, the times, the masses, and the forces are such that the unit of force gives to the unit of mass, in the unit of time, the unit of velocity. If, after having obtained the value of the product M T, we obtain those of the relation $\frac{M}{T}$, by eliminating M we shall obtain T. Now this relation will be given by the observation of a second needle, placed at the same time under the influence of the former and of terrestrial magnetism. But, before going further, it is proper to point out how we should

proceed in order to deduce from observation the different terms of the formula

$$MT = \frac{\pi^2 K}{t^2}.$$

We must, in fact, take account of the torsion of the thread, which diminishes the time of the oscillations. Let us suppose the needle in equilibrio under the double action of terrestrial magnetism and torsion; let u be the angle which the magnetic axis of the needle makes with the magnetic meridian; and v the angle which is made also with the meridian by the diameter, taken at the fixed extremity of the thread, which, if the latter were without torsion, would be parallel to the lower diameter, which we have chosen.

The moment of rotation of torsion is $\theta (v-u)$, θ being a constant co-efficient; that of terrestrial action is $MT \sin. u$; we then have, $MT \sin. u = \theta (v-u)$; or, on account of the smallness of u,

$$MT\, u = \theta (v-u)$$

$$1 + \frac{MT}{\theta} = \frac{v}{u}.$$

As it is difficult to obtain the exact values of v and u, it is better to observe differences; and we obtain

$$1 + \frac{MT}{\theta} = \frac{v' - v''}{u' - u''}.$$

On the other hand, the time, t, of an oscillation, observed and reduced to an infinitely small amplitude, satisfies the formula

$$t = \pi \sqrt{\frac{K}{MT + \theta}}.$$

The time, t', that would have been found, if there had been no torsion, is given by this formula:—

$$t' = \pi \sqrt{\frac{K}{MT}};$$

we then have

$$\frac{t'}{t} = \sqrt{1 + \frac{\theta}{MT}};$$

and by making $\frac{MT}{\theta} = n$, a number which results from the observation of the angles u and v, we obtain

$$\frac{t'}{t} = \sqrt{\frac{n+1}{n}}.$$

If the oscillating body is a needle of regular form and homogeneous mass, we can find its moment of inertia by known methods; but in Gauss's apparatus (Unifilar Magnetometer, Vol. III. p. 212.) the needle is joined to a very complicated system. In order to determine the moment of inertia of the oscillating mass, a stem of wood is fixed transversely to the needle, upon which stem two determinate weights are made to rest by sharp points, and at equal distances from the point of suspension.

Distinguishing the moment of inertia sought by K, the mass of each of the two weights by m, the distance of their points of application from the point of suspension by r, and the sum of the moment of inertia of the wooden stem in relation to the axes of suspension, and of the moments of the weights in relation to the vertical axes of each of them by C, the moment of inertia of the whole apparatus is

$$K + C + 2\,m r^2.$$

If therefore t, t', and t'' are the times of oscillation observed and corrected for the successive cases, in which the wooden stem is not placed on, wherein the weights are at a distance r', and finally wherein they are at a distance r'', we obtain the three equations

$$\begin{aligned} MT\,t^2 &= \pi^2 K, \\ MT\,t'^2 &= \pi^2 (K + C + 2\,m r'^2), \\ MT\,t''^2 &= \pi^2 (K + C + 2 m r''^2); \end{aligned}$$

whence is deduced MT and K, which when once known becomes a constant of the apparatus.

We may add that, for greater precision, we must give to r several different values, and determine, by the method of least squares, the unknown auxiliaries which will best satisfy all the equations; then, as these various operations demand considerable time, it is necessary to make another needle oscillate simultaneously, so as to be able to reduce the successive observations to the mean value of the intensity of terrestrial magnetism for one of them.

Thus it is that Gauss obtained with the unifilar magnetometer, from a series of observations made September 11, 1832,

$$TM = 179575250.$$

He had taken for the unit of time, of length, and of mass, the second, the millimètre, and the mass of a millegramme. According to what we have said, the unit of force is therefore the

force which, acting during a second upon the mass of a millegramme, will give to it a velocity of a millimetre per second; that is to say, the weight of a milligramme, divided by the velocity acquired at the end of a second by a body falling in vacuo. This velocity is 9811·03 at Göttingen; so that, taking for a unit the weight of a milligramme at Göttingen,

$$T M = 18302{\cdot}29,$$

We are now about to see how the relation of these two same quantities may be deduced, with more calculation, it is true, than their products, but with as much accuracy, from the position of equilibrium that a second needle assumes (No. 2.) under the double action of terrestrial magnetism and of the needle that we have caused to oscillate (No. 1.). In what is about to follow, Gauss leaves undetermined the law of the variation of the magnetic forces with distance; and his first observations had for their object to finish this.

The question is to establish the conditions of equilibrium of the needle (No. 2.) movable around a vertical axis, and having its magnetic axis horizontal. The forces that act upon it are, terrestrial magnetism, the action of the fixed needle (No. 1.) having its magnetic axis in the same horizontal plane, and, finally, the torsion of its suspension wire. In order that it may be regarded in equilibrio, according to the principle of virtual velocities, it is necessary and is sufficient that the sum of the products of each of the foci by the infinitely small displacement of its point of application, projected upon the direction of the force, be null, for every movement compatible with the connections of the bodies; and, in this case, it will be for every motion of rotation around the vertical axis, which we may consider as fixed.

Let us take for the axis of z the suspension wire, for the axis of x the magnetic meridian, and for the axis of y a line perpendicular to the meridian; the origin is at h in the middle of the thickness of the needle.

Let us express the conditions deduced from the principle of virtual velocities: —

1st. For the forces arising from terrestrial magnetism; let e be an element of free magnetism of the needle (No. 2.) whose co-ordinates are x, y, z.

$T e d x$ is the product of the force by the displacement of the

point of application, projected upon its direction. We have, therefore, for the whole needle, the term

$$\Sigma \, \mathrm{T} \, e \, d \, x.$$

2nd. For the action of the needle (No. 1.): —

Let E be an element of free magnetism of the needle (No. 1.), which has for its co-ordinates X, Y, Z.

The action of E upon e is

(by placing $r = \sqrt{(\mathrm{X}-x)^2+(\mathrm{Y}-y)^2+(\mathrm{Z}-z)^2}$) $\frac{\mathrm{E}\,e}{r^n}$, ($n$ being really equal to 2.). The product desired is, therefore,

$$\frac{\mathrm{E}\, e \, d \, r}{r^n};$$

and for the sum of the two needles we have the double sum

$$\Sigma \, \Sigma . \, \frac{\mathrm{E}\, e \, d \, r}{r^n}.$$

3rd. For the torsion, according to what we have seen, u being the angle of the magnetic axis of the needle, in equilibrio with the magnetic meridian, and N the angle of collimation, we have the term

$$\theta \, (\mathrm{N} - u) \, d \, u.$$

The equation of equilibrium is, therefore,

$$\Sigma \mathrm{T} e dx + \Sigma \Sigma \frac{\mathrm{F} e d r}{r^n} + \theta (\mathrm{N} - u) du = 0.$$

The question now is to express both x and r in the function of u, in the two former terms. It is more convenient for doing this to integrate them in respect to x and to r, and to expand hereafter the deduction in respect to u.

We shall thus have

$$\Sigma \mathrm{T} e x \text{ and } \Sigma \Sigma \frac{\mathrm{E}\, e}{(n-1) r^{n-1}}.$$

Let us now conceive a system of rectangular axes having the same origin and the same axes of z' that precede it, but movable with the needle, whose magnetic axis will be the axis of x'; let us take an analogous system for the needle (No. 1.); their origin will be at H in the same horizontal plane as h; and its position will be determined on the one hand, by the length, R, of the right line h' H, h' being determined in its turn by the co-ordinates a,

β; and, on the other hand, by the angle, ψ, of the right line R with the magnetic meridian. The axis of X′ of this system will coincide with the magnetic axis of the needle (No. 1.), and will be determined by the angle U, which it makes with the magnetic meridian (*fig.* 447.). The angles u, U, and ψ are counted positively to the east of the magnetic meridian.

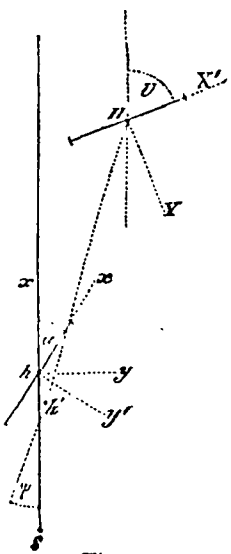

Fig. 447.

In order to pass from x to x', we have the equations

$$x = x' \cos. u - y' \sin. u.$$
$$y = x' \sin. u + y' \cos. u.$$
$$z = z';$$

and in order to pass from X to X′, we have

$$X = \alpha + R \cos. \psi + X' \cos. U - Y' \sin U.$$
$$Y = \beta + R \sin. \psi + X' \sin. U + Y' \cos. U.$$
$$Z = Z'$$

Let us now substitute for x and X their values. For the term $\Sigma T e x$, there comes

$$\Sigma T e x' \cos. u - \Sigma T e y' \sin. u.$$

Now, $\Sigma T e x' = T m$, designating by m the maximum magnetic moment of the needle (No. 2.); and $\Sigma T e y' = 0$.

There then remains $m T \cos. u$, the deduction of which in respect of u is $m T \sin. u$.

Let us now take the term $-\Sigma\Sigma \frac{E e}{(n-1) r^{(n-1)}}$; we have $r^2 = (X - x)^2 + (Y - y)^2 + (Z - z)^2$.

By substituting for the co-ordinates their values, by making the calculations, and placing for simplification

$$h = \alpha \cos. \psi + \beta \sin. \psi + X' \cos. (\psi - U) + Y' \sin. (\psi - U) - x' \cos. (\psi - U) - y' \sin. (\psi - U)$$

$$l = \{\alpha \sin. \psi - \beta \cos. \psi + X' \sin. (\psi - U) - Y' \cos. (\psi - U) - x' (\psi - u) - y' \cos (\psi - u)\}^2 + (Y' - y')^2,$$

we have: $r^2 = (R + h)^2 + l$.

As in the experiments R will be always too great, $\frac{1}{r^{n-1}}$ is de-

veloped in a very convergent series, according to the negative and increasing powers of R.

$$r^{-(n-1)} = r^{2\,-\frac{(n-1)}{2}} = \{(\mathrm{R}+k)^2 - l\}^{-\frac{(n-1)}{2}} = \mathrm{R}^{-(n-1)} - (n-1)\,k\,\mathrm{R}^{-n}$$

$$+ \left\{\frac{(n^2-n)}{2}k^2 - \frac{(n-1)}{2}l\right\}\mathrm{R}^{-(n+1)} - \left(\tfrac{1}{6}(n^3-n)\,k^3 - \tfrac{1}{2}(n^2-1)\,k\,l\right)\mathrm{R}^{-(n+2)} + \&c.$$

If we suppose k and l replaced by their values, we see that $\Sigma\Sigma\frac{\mathrm{E}e}{r^{(n-1)}}$ is composed of a series of terms the general expression of which is

$$\frac{\Sigma\Sigma \mathrm{E}e x'^{\lambda} y'^{\mu} z'^{\nu}\ \mathrm{X}'^{\lambda'}\mathrm{Y}'^{\mu'}\mathrm{Z}'^{\nu'}}{\mathrm{R}^{p}} = \frac{\Sigma e x'^{\lambda} y'^{\mu} z'^{\nu} \cdot \Sigma \mathrm{E}\mathrm{X}'^{\lambda'}\mathrm{Y}'^{\mu'}\mathrm{Z}'^{\nu'}}{\mathrm{R}^{p}}.$$

In the most general case, all that can be established is reduced to equations :—

$\Sigma e = 0$	$\Sigma e x' = m$	$\Sigma e y' = 0$
$\Sigma e z' = 0$	$\Sigma \mathrm{E} = 0$	$\Sigma \mathrm{E}\mathrm{X}' = \mathrm{M}$
$\Sigma \mathrm{E}\mathrm{Y}' = 0$	$\Sigma \mathrm{E} z' = 0$	

In the particular case in which the figure of each of the two needles, as well as the distribution of its magnetism, is symmetrical in respect to the origin of its system of axes, we have

$$\Sigma e x'^{\lambda} y'^{\mu} z'^{\nu} = 0,$$

and

$$\Sigma \mathrm{E}\mathrm{X}'^{\lambda'}\mathrm{Y}'^{\mu'}\mathrm{Z}'^{\nu'} = 0,$$

for every value made of the numbers $\lambda+\mu+\nu$ and $\lambda'+\mu'+\nu'$.

Thus, in this case, if we have at the same time $\alpha = 0$ and $\beta = 0$, the co-efficients of the terms $\mathrm{R}^{-(n+2)}$, $\mathrm{R}^{-(n+4)}$, &c. will disappear. In the general case, these co-efficients will always be very small; the co-efficients of the first two terms of the series are null, and the principal term is

$$\frac{\Sigma\Sigma \mathrm{E}e}{(n-1)}\left\{\frac{(n^2-n)}{2}k^2 - \frac{(n-1)}{2}\,l\right\}\mathrm{R}^{-(n+1)} =$$

$$\tfrac{1}{2}\,\mathrm{R}^{-(n+1)}\Sigma\Sigma \mathrm{E}e\,(n\,k^2 - l) =$$

$$m\,\mathrm{M}\,\mathrm{R}^{-(n+1)}\{n\cos.(\psi-\mathrm{U})\cos.(\psi-u) - \sin.(\psi-\mathrm{U})\sin.(\psi-u)\},$$

the derivation of which in respect to u is

$$-\mathrm{M}\,\mathrm{R}^{-(n+1)}\{n\cos.(\psi-\mathrm{U}) + \sin.(\psi\,\mathrm{U})\cos.(-\psi-u)\}.$$

We have, therefore, for the development of the terms of the equation of the equilibrium of the needle relative to the action of the other needle, a series of the form

$$f\,\mathrm{R}^{-(n+1)} + f'\,\mathrm{R}^{-(n+2)} + f''\,\mathrm{R}^{-(n+3)}, \text{ \&c.}$$

in which the co-efficients f are rational functions of the sines and co-sines of the angles ψ, U, and u, and constants of the two needles.

We see, moreover, that in the particular case of equation indicated above, f', f''', &c., are null; that in the general case they are too small; and further, that, if all the other quantities remain the same, ψ is increased by 180°, f, f'' &c., retaining the same values, and f', f''' interchanging signs.

The equation of equilibrium is, therefore,

$$-m\,\mathrm{T}\sin. u + f\,\mathrm{R}^{-(n+1)} + f'\,\mathrm{R}^{-(n+2)} + \text{\&c.} - \theta(u - \mathrm{N}) = 0.$$

As u and N are very small, $\theta \sin.(u - \mathrm{N})$ may be substituted for $\theta(u - \mathrm{N})$.

Let u_0 be the value of u, by which the needle (No. 2.) is in equilibrio under the action of terrestrial magnetism and of torsion in the absence of the needle (No. 1.). We have

$$m\,\mathrm{T}\sin. u_0 + \theta \sin.(u_0 - \mathrm{N}) = 0.$$

On account of this equality, the equation

$$m\,\mathrm{T}\sin. u + \theta \sin.(u - \mathrm{N}) = \{m\,\mathrm{T}\cos. u_0 + \theta\cos.(u_0 - \mathrm{N})\}\sin.(u - u_0)$$

is an identity; and as u_0 is very nearly null, the second number may be written, $(m\,\mathrm{T} + \theta)\sin.(u - u_0)$. Then the equation of equilibrium becomes

$$(m\,\mathrm{T} + \theta)\sin.(u - u_0) = f\,\mathrm{R}^{-(n+1)} + f'\,\mathrm{R}^{-(n+2)} + \text{\&c.}$$

If we retain only the co-efficient f, by substituting in its value for the angle $\psi - u$ the value $(\psi - u_0) + (u_0 - u)$, we have

$$(m\,\mathrm{T}+\theta)\sin.(u-u_0) = m\,\mathrm{M}\,\mathrm{R}^{-(n+1)}\cos.(u-u_0)\{n\cos.(\psi-\mathrm{U})\sin.(\psi-u_0) + \sin.(\psi-\mathrm{U})\cos.(\psi-u_0)\} - \sin.(u-u_0)\{n\cos.(\psi-\mathrm{U})\cos.(\psi-u_0) - \sin.(\psi-\mathrm{U})\sin.(\psi-u_0)\};$$

whence we deduce

$$tg\,(u-u_0) = \frac{m\,\mathrm{M}\{n\cos.(\psi-\mathrm{U})\sin.(\psi-u_0) + \sin.(\psi-\mathrm{U})\cos.(\psi-u_0)\}\mathrm{R}^{-(n+1)}}{m\,\mathrm{T}+\theta+m\,\mathrm{M}\{n\cos.(\psi-\mathrm{U})\cos.(\psi-u_0) - \sin.(\psi-\mathrm{U})\sin.(\psi-u_0)\}\mathrm{R}^{-(n+1)}};$$

or, by neglecting from the denominator the factor $\mathrm{R}^{-(n+1)}$,

$$tg\,(u-u_0) = \frac{m\,\mathrm{M}}{m.\,\mathrm{T}+\theta}\{n\cos.(\psi-\mathrm{U})\sin.(\psi-u_0) + \sin.(\psi-\mathrm{U})\cos.(\psi-u_0)\}\frac{\mathrm{R}^{-(n+1)}}{\mathrm{F}\mathrm{R}^{-(n+1)}}.$$

And we have $\mathrm{F} = \dfrac{f}{m\,\mathrm{T}+\theta}$, by changing u into u_0.

If we desire to take a greater number of terms, it is necessary to accomplish the division; and, for simplification, by placing

$$g = m\ \mathrm{M}\{n \cos.(\psi - \mathrm{U}) \cos.(\psi - u_0) - \sin.(\psi - \mathrm{U}) \sin.(\psi - u_0)\},$$

we have

$$\begin{array}{l|l} f\mathrm{R}^{-(n+1)} + f'\mathrm{R}^{-(n+2)} \ldots\ldots + f_n\mathrm{R}^{-(2n+1)} + \dfrac{f_{n+1} - gf}{m\mathrm{T}+\theta} & \mathrm{R}^{-(2n+2)} + \ldots \\ \hline m\mathrm{T} + \theta + g\mathrm{R}^{-(n+1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & \\ \dfrac{f\mathrm{R}^{-(n+1)}}{m\mathrm{T}+\theta} + \dfrac{f'\mathrm{R}^{-(n+2)}}{m\mathrm{T}+\theta} + \ldots \dfrac{f_n\mathrm{R}^{-(2n+1)}}{m\mathrm{T}+\theta} + \left\{\dfrac{f'_{n+1}}{m\mathrm{T}+\theta} - \dfrac{fg}{(m\mathrm{T}+\theta)^2}\right\}\mathrm{R}^{-(2n+2)}. & \end{array}$$

Thus we have $t\,g\,(u - u_0) = \mathrm{F}\,\mathrm{R}^{-(n+1)} + \mathrm{F}'\,\mathrm{R}^{-(n+2)} \ldots\ldots$, in which the co-efficients F are derived respectively from the terms f, in which u is changed into u_0; and this, as far as the term to $\mathrm{R}^{-(2n+1)}$; but setting out thence, terms of another kind are introduced.

It is here convenient to make a remark which will be of service hereafter. We know that by changing the sign of ψ, f, f'', f^{IV}, &c., keep the same values, whilst f', f''', &c., change signs. Now, if n is even (which is the case), the co-efficient of $\mathrm{R}^{-(2n+2)}$ in the series of $t\,g\,(u - u_0)$ contains a co-efficient of the kind f', and a co-efficient of the kind f; therefore, setting out from this term, we no longer obtain terms respectively equal and with contrary signs by changing the sign of ψ.

We have therefore $t\,g\,(u - u_0) = \mathrm{F}\,\mathrm{R}^{-(n+1)} + \mathrm{F}'\,\mathrm{R}^{-(n+2)} +$, &c.

We now see that, if we make R to vary, and if we observe the angles $(u - u_0)$, we have a series of equations whence we may deduce F, and we have then

$$\frac{\mathrm{M}}{\mathrm{T}} = \left(1 + \frac{\theta}{m\,\mathrm{T}}\right)\frac{\mathrm{F}}{n \cos.(\psi - \mathrm{U}) \sin.(\psi - u_0) + \sin.(\psi - \mathrm{U}) \cos.(\psi - u_0)};$$

$\dfrac{\theta}{m\,\mathrm{T}}$ will be determined as we have seen for the needle (No. 1.).

Thus, theoretically, the problem is solved; but, instead of comparing u and u_0, it is better to compare together two opposite deviations u' and u'', obtained by increasing U by two right angles, then making anew this double observation, after having increased ψ by two right angles, which gives u''' and u^{IV}. In fact, according to the remark above, we obtain

$$t\,g\,(u' - u_0) = \mathrm{F}\,\mathrm{R}^{-(n+1)} + \mathrm{F}'\,\mathrm{R}^{-(n+2)} \ldots\ldots + \left\{\frac{f(n-1)}{m\,\mathrm{T}+\theta} - \frac{fg}{(m\,\mathrm{T}+\theta)^2}\right\}\mathrm{R}^{-(2n+2)} \ldots\ldots$$

$$t\,g\,(u''' - u_0) = \mathrm{F}\,\mathrm{R}^{-(n+1)} - \mathrm{F}'\,\mathrm{R}^{-(n+2)} \ldots\ldots + \left\{\frac{-f(n+1)}{m\,\mathrm{T}+\theta} - \frac{fg}{(m\mathrm{T}+\theta)^2}\right\}\mathrm{R}^{-(2n+2)} \ldots$$

By the series, arc. $t\,g\,x = x - \frac{x^3}{3}$ . . . . we see that the development of $u - u_0$ is the same as that of $t\,g\,(u - u_0)$ to the term in $R^{-(3n+3)}$; therefore,

$$(u' - u_0) + (u''' - u_0) = 2\,F\,R^{-(n+1)} + 2\,F''R^{-(n+3)} \ldots - \frac{2fg}{m\,T + \theta}\,R^{-(n+2)}.$$

If we now change the sign of U, we shall have

$$(u'' - u_0) + (u^{IV} - u_0) = -2\,F\,R^{-(n+1)} + L\,R^{-(n+3)} \ldots - \frac{2fg\,R^{-(2n+3)}}{(m\,T + \theta)^2};$$

L designating any co-efficient, whose value we do not determine.

The last term does not change signs, because both f and g change. We shall have, on deducting these two developments and dividing by 4,

$$\frac{1}{4}(u' - u'' + u''' - u^{IV}) = F\,R^{-(n+1)} + L\,R^{-(n+3)} + \ldots \ldots L_{\frac{(n+2)}{2}} R^{-(2n+3)} + \ldots$$

and consequently also

$$t\,g\,\frac{1}{4}(u' - u'' + u''' - u^{IV} = F\,R^{-(n+1)} + L'R^{-(n+3)} + \ldots L_{\frac{(n+2)}{2}} R^{-(2n+3)}.$$

So that we obtain thus a development in which half of the co-efficients have disappeared as far as the term $m\,R^{-(2n+3)}$, which to this extent will diminish the chances of errors.

It remains to determine the value to be given to ψ and to U, which must be such that the errors in their measure influence in the least possible manner the values of F; for then the value of U, for a value given to ψ, must render F a maximum. We have thus

Cot. $d\,(\psi - U) = n\,t\,g\,(\psi - u)$; whence

$$F = \pm \frac{m\,M}{m\,T + \theta} \sqrt{n^2 \sin.^2(\psi - u_0) + \cos.^2(\psi - u_0)}.$$

The value given to ψ should therefore render this expression a maximum or a minimum; which takes place

1st. In making $(\psi - u_0) = 90°$ or $270°$; in this case $F = \frac{n\,m\,M}{m\,T + \theta}$.

2nd. In making $(\psi - u_0) = 0$ or $180°$; in this case $F = \frac{m\,M}{m\,T + \theta}$.

There are then two methods of observation (*fig.* 448.). In each

of the positions indicated by H_1 and H_2 the fixed needle must assume two positions diametrically opposite.

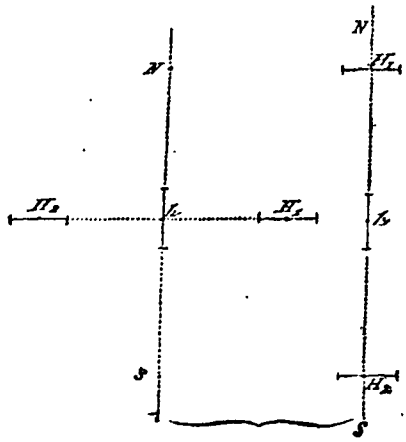

Fig. 448.

The former method is the more advantageous; for it gives to F a value n times greater, and the errors are consequently diminished in the relation of 1 to $\frac{1}{n}$.

The first experiments of Gauss have had for their object to determine the value of n, left undetermined in all these calculations. The following is the Table of his observations, by which he has employed simultaneously the two methods. In the Table

$$v = \tfrac{1}{4}(u' - u'' + u''' - u^{iv}).$$

R. m.	v (1st method).	v (2nd method).
1·3	2° 13′ 51″·2	1° 57′ 24″·8
1·4	1 47 28 ·6	1 29 40 ·5
1·5	1 27 19 ·2	1 10 19 ·3
1·6	1 12 7 ·6	0 55 58 ·9
&c.	&c.	&c.

We see at first that the numbers of the second column are almost double those of the third; which shows that n must be equal to 2.

By giving to n the value of 2, Gauss found for the co-efficients the following values:—

$tg\, v = 0{\cdot}086870\, R^{-3} - 0{\cdot}002185\, R^{-5}$, for the first method.

And the following Table gives the comparative values of the angles ν, observed and calculated after this formula:—

R. m.	Observed values of ν.	Calculated values of ν.	
1·3	2° 13′ 51″·2	2° 13′ 50″·4	+0″·8
1·4	1 47 28 ·6	1 47 26 ·1	+4 ·5
1·5	1 27 19 ·1	1 27 28 ·7	−9 ·6
1·6	1 12 7 ·6	1 0 14 ·9	−3 ·3

No doubt, therefore, can remain as to the value of n; and the law of magnetic attractions is thus found to be confirmed. Besides, we see by this that if we do not assume the values of R to be smaller than four times the length of the needles (they were 0·3m.), two terms of the series are sufficient.

The following, then, are the elements of a determination of the absolute value of the intensity of terrestrial magnetism :—

$$\mathrm{R} = 1\overset{\text{m.}}{\cdot}2 \qquad \nu = 3^\circ\,42'\,19''\cdot4$$
$$\mathrm{R}' = 1\cdot6 \qquad \nu' = 1^\circ\,34'\,19''\cdot3.$$

We have, therefore,

$$tg\,\nu = \mathrm{F}\mathrm{R}^{-3} + \mathrm{L}'\mathrm{R}^{-5}, \text{ or } \mathrm{R}^5\,tg\,\nu = \mathrm{F}\mathrm{R}^2 + \mathrm{L}'.$$

In like manner, $\mathrm{R}'^5\,tg\,\nu' = \mathrm{F}\mathrm{R}'^2 + \mathrm{L}'$; whence

$$\mathrm{F} = \frac{\mathrm{R}^5\,tg\,\nu - \mathrm{R}'^5\,tg}{\mathrm{R}^2 - \mathrm{R}'^2} = 113056200.$$

Thence $\frac{\mathrm{M}}{\mathrm{T}} = 56606437.$

We have besides $\mathrm{MT} = 179770600$; whence $\mathrm{T} = 1{\cdot}782088$.

And we remember that the unit is the force which, acting only upon the unit of free magnetism, would produce an action equal to the unit of force.

To sum up: The determination of the absolute intensity of terrestrial magnetism is composed of two very distinct operations. In the first we observe the number of oscillations that are made by a needle in a given time. This number depends upon the intensity of terrestrial magnetism, and on the constitution of the needle; that is to say, the static moment of its elements of free magnetism and of its moment of inertia. As we may easily determine this moment of inertia, we obtain the static moment of the magnetism of the needle multiplied by the intensity of terrestrial magnetism. The second operation consists in observing the posi-

tions of equilibrium that a needle assumes subjected to the action of terrestrial magnetism, and to that of the needle that is made to oscillate: this latter action depends upon the distribution of free magnetism in the two needles,—on the distance of the centres,—on the position of the magnetic axes in respect to the right line which unites the centres,—and, finally, on the law which magnetic attractions and repulsions follow. When once this law is known, we find that the total action of the fixed needle upon the movable needle, in proportion as the distances of the centres increase, tends to vary in inverse ratio of the cube of the distance; so that this moment of rotation, taken for a distance sufficiently great and multiplied by the cube of the distance, may be considered as a constant product; and this product, on placing the magnetic axes of the two needles in directions relatively determined, is expressed by the product of the static moments of the magnetism of the two needles. As, besides, the moment of rotation exercised by terrestrial magnetism upon the movable needle is expressed by the product of the static moment of the needle and of terrestrial magnetic intensity, and that the position of equilibrium of the needle enables us to know the relation of the two moments of rotation; whence we conclude the relation of the two quantities, the product of which we have obtained by the former operation.

NOTE B. (P. 215.)

Note on the Bi-filar Magnetometer.

The object of this note is to show how we find the value of the couple that originates, under the action of gravity, from the mode of suspension of the magnetized bars in the bi-filar magnetometer; and how we deduce from it the intensity of terrestrial magnetism, and the variations of this element.

Fig. 449. represents the position of equilibrium that results to the magnetometer from the action of gravity alone; that is to say, which it will assume, if we suppose the bar to be deprived of magnetism. We admit that the two upper points of attachment of the threads, A and B, are upon a same horizontal line, and the lower points of attachment, *a* and *b*, are both situated at the same distance from the centre of gravity, *o*, of the bar. In order that equilibrium may take place, it is necessary that the two wires intersect each other

on the vertical, passing through the centre of gravity in such a manner that the weight of the bar transported into the point of intersection is decomposed into two forces, directed according to the prolongation of the threads, which require that these two threads be in a same vertical plane, and that they be symmetrically placed on either side of the vertical of the point *o*, that is to say, that it shall intersect in the middle the lines AB and *ab*.

Fig. 449.

Let us now conceive that a horizontal couple comes to act upon the needle: it will produce a movement of torsion of the suspension system; and the threads will cease to be found in a vertical plane; at the same time, the point *c*, in the middle of *ab*, will mount up by a very small quantity along the vertical. Let us now suppose the system in equilibrio, under the influence of all the forces that are acting upon it; and let α be the angle through which the needle has turned; 2Δ the length AB the upper distance apart of the threads; 2δ the length *a b* the lower distance apart of the threads; P the weight of the bar; T the common tension of each of the threads; L their length; *l* this same length projected upon the vertical.

Let us (*fig.* 450.) draw through the point *c* the line A′*c*B′ equal and parallel to ACB; let us join AA′ and BB′; AA′BB′ will be a vertical rectangle, and the lines A′*c*B′ and *acb* will be in a same horizontal plane. The weight P may be resolved into two forces, equal to $\frac{P}{2}$, applied to *a* and *b*; the tension, T, directed according to *a*A, is decomposed according to the vertical and horizontal; the vertical component has for its value T cos. A′A*a*, that is to say, $T\frac{l}{L}$.

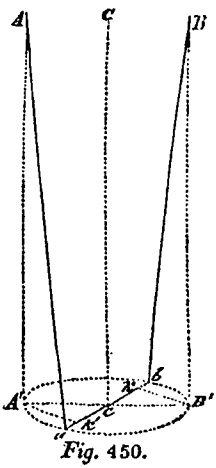

Fig. 450.

Now, the system being in equilibrio, the resultant of the forces applied to *a* must be null; the proportion of the resultant upon the vertical must be null also; and consequently we have

$$\frac{Tl}{L} = \frac{P}{2}.$$

From the point A′, obeying a perpendicular A′a upon $a\,c\,b$, the horizontal component of the tension that acts according to a A′ may itself be decomposed according to $a\,\alpha$ and a A′; it will be exactly the same at b, so that we shall have two equal foci, directed according to $a\,a$ and $b\,\beta$, which destroy each other; and two others, the direction of which is perpendicular to that of the needle, which constitute a couple, making equilibrium to the couple of terrestrial magnetism. The expression of this component, perpendicular to the needle, is, therefore,

$$\mathrm{T}\,\frac{\mathrm{A}'a}{\mathrm{L}} \times \frac{\mathrm{A}'a}{\mathrm{A}'a} = \mathrm{T}\,\frac{\mathrm{A}'a}{\mathrm{L}}.$$

By calling K the value of the horizontal bi-filar couple, which tends to bring back the needle to its position of equilibrium, we shall have, therefore,

$$\mathrm{K} = 2\,\mathrm{T} \times \frac{\mathrm{A}'a}{\mathrm{L}} \times ac = 2\,\Delta\,\delta \sin. a\,\frac{\mathrm{T}}{\mathrm{L}};$$

and, by substituting for T its value, deduced from the equation which made the vertical components equal, we have

$$\mathrm{K} = \frac{\Delta\,\delta\,\mathrm{P} \sin.\, a}{l}; \qquad \text{——}$$

an equation, to which it is necessary to annex the equation of condition:—

$$l^2 = \mathrm{L}^2 - \Delta^2 - \delta^2 + 2\,\Delta\,\delta \cos.\, a.$$

In general, Δ and δ are so small in respect to L, that we may without error suppose $l = \mathrm{L}$; and we may add that the torsion proper to each thread introduces also two small oblique couples; but so feeble that their action may be neglected.

For all the positions which the bar can assume under the combined action of the two couples, the magnetic and the bifilar, there is one position particularly interesting in respect to observations, which is that for which the magnetic axis of the needle is normal to the magnetic meridian. We see in fact that, for this position, all the disturbing magnetic forces, which alter the declination without modifying the horizontal intensity, leave the bar completely motionless, since the components of each disturbing couple are applied in directions directly contrary one to the other at the two extremities of the magnetic axis; on the contrary, the

foci which the horizontal intensity attains will have their entire effect, and will manifest their action by angular displacements of the bar around the axis C *c* O.

Let us then conceive that by trials, that is to say, by making the position of equilibrium gradually to vary, depending, as it does, on the mode of suspension only, we have brought the needle into the position indicated. The moment of this magnetic couple is a maximum ; and, designating it by M, we have (since the bar is in equilibrio)

$$M = \frac{\Delta \delta P \sin. a}{l} \quad (1) ;—$$

an expression which frequently assumes the form,

$$\frac{d^2 P \sin. a}{L} ;$$

designating by d the distance apart of the threads when we suppose them parallel ; and by substituting L for l, which differs very little from it, as we have seen.

We see then that the direct measure of the different quantities that enter into this expression, enable us to find the value of the magnetic couple, as well as the observation of the duration of a certain number of oscillations ; and, as the method, which serves for the measure of the angles in the magnetometer, admits of very great precision, and as we may obtain also the other elements of the formula with every desired rigour, it follows that we arrive also at a value of the directive force, which acts upon the magnetized bar.

We are now about to see how the bi-filar magnetometer is employed in order to obtain the variations of horizontal intensity. The magnet M is the product of the magnetism proper of the bar, which we will suppose invariable, by the variable horizontal intensity of terrestrial magnetism. When, by virtue of this variation, M varies, the angle a also varies. By differentiating then the equation, by making a, l, and M in it to vary, we have,

$$dM = \Delta \delta P \left\{ \frac{l \cos. a da - \sin. a dl}{l^2} \right\}$$

The equation of condition, of which we have spoken above, gives

$$dl = - \frac{\Delta \delta \sin. a da}{l} ;$$

so that, by substituting for $d\,l$ its value, we find

$$d\mathrm{M} = \Delta\delta\mathrm{P}\left\{\frac{\cos.\,a\,da}{l} + \frac{\Delta\delta\sin.^2 a\,da}{l^3}\right\}(2);$$

and by dividing (2) by (1),

$$\frac{d\mathrm{M}}{\mathrm{M}} = \left\{\cot.\,a + \frac{\Delta\delta\sin.\,a}{l^2}\right\}da.$$

If we neglect the very small fraction $\frac{\Delta\delta}{l^2}$,

$$\frac{d\mathrm{M}}{\mathrm{M}} = \cot.\,a\,da.$$

Finally, it is always possible to establish the conditions of equilibrium in such a manner that, for the mean value of M, we have $a = 45°$, either by modifying the distances Δ, δ, or by making the length of the threads vary, or again by adding weights to the bar. In this manner the equation produced becomes

$$\frac{d\mathrm{M}}{\mathrm{M}} = da.$$

We have mentioned how we observe with a horizontal scale, a mirror, and a telescope the angular displacements of the bar. If D is the distance, expressed in millimetres, which separates the mirror from the scale, and consequently also the mirror from the telescope, a reading of n millimetres in the telescope will correspond with a value of $d\,a$ equal to $\frac{n}{2\mathrm{D}}$. We will commence at $\frac{d\mathrm{M}}{\mathrm{M}} = da$; there results from this $\frac{d\mathrm{M}}{\mathrm{M}} = \frac{n}{2\mathrm{D}}$; and we have thus the fraction by which the horizontal magnetic intensity has changed, its mean value being taken as unity.

NOTE C. (P. 257.)

Relative to the Determinations of the Magnetic Elements of the Principal Stations of the Terrestrial Globe.

We have thought that a note, in which we might find the value of the magnetic elements resulting from recent observations in the greater portion of the known stations, might present some interest. Pressed by the publication of this work, we shall give all the information that we have, up to this time, been able to collect,—thanks to the readiness with which it has been furnished to us.

Observatory of Paris.

We have already had occasion to mention the magnetic observations that are made at Paris, with remarkable accuracy, under the direction of M. Liais. In 1855, MM. Goujon and Liais determined the local influence for the different apartments in which magnetic observations are made. For this purpose they chose four intersecting stations, which were Montrouge, the plain of St. Denis, Vincennes, St. Cloud ; and they there observed, in each, the declination, the inclination, and the magnetic intensity. A formula of interpolation enabled them to deduce from values of these elements that which they ought to obtain in the various localities of the Observatory ; and, by comparing these values with those actually observed, they determined the local errors. With regard to the mode of observation, we shall not return to this subject, which we have sufficiently developed.

Declination.	In 1854	20° 1′ 55″	Observed by MM. Goujon and Liais.
	In 1855	19 57 45	„ „ „
	In 1856	19 48 23	Observed by M. Liais.
Inclination.	In 1854	66 25′·3	Observed by MM. Goujon and Liais.
	In 1855	66 22 ·5	„ „ „
	In 1856	66 19 ·2	Observed by M. Liais.
Horizontal intensity.	May, 1856 . . .	1·8882	„ „

The intensity is expressed in absolute value. The units are the same as those of Gauss,—the millimètre and the milligramme.

Observatory of Greenwich.

Lat. 51° 28′ 39″. Long. from the meridian of Paris, 2° 20′ 24″ W.

The following numbers of the magnetic elements represent the mean of all the observations of the year 1856:

Declination	21°42′ 52″
Inclination	68 31
Horizontal intensity	3·822

The absolute value of the horizontal intensity is here expressed by taking for units the English foot and grain.

M. Quetelet, Director of the Observatory of Brussels, publishes every year the results of a great number of magnetic observations, made either at Brussels itself, under his direction, or by various observations that are communicated to him. We extract from these notices the following Tables.

Observatory of Brussels.

Lat. 50° 51′ 11″. Long. from the meridian of Paris, 2° 1′ 46″ E.

Epochs.	Declination.	Inclination.
March, 1852	20°18′·2	67°48′·6
April, 1853	20 6·0	67 47·6
March, 1854	19 57·7	67 45·0
April, 1855	19 57·5	67 43·0

Magnetic Elements for the date of 1853·66 *determined by M. Ermann of Berlin.*

Stations.	Latitude	Long. E. of Paris.	Inclination.	Western Declination.	Horizontal intensity (absolute value; units of Gauss.).
Berlin	52°31′ 55″	11° 3′ 11″	67°29′·72	14°57′ 3″	1·7900
Paris	48 50 16	- -	66 25·29	20 17 51	1·8503
Marseilles	43 18 10	356 58 0	61 57·47	17 35 35	2·1026
Carthagena	37 35 42	356 40 30	77 55·74	18 53 20	2·3231
Malaga	36 43 15	353 14 34	58 19·16	20 11 41	2·3436
Santander	43 29 57	351 27 22	63 38·39	21 13 31	2·0493
Nantes	47 13 18	356 6 44	66 2·95	21 28 57	1·9360

Magnetic Observations in the North of Germany and Holland. By M. Quetelet. 1856.

Stations.	Latitude.	Longitude from Paris.	Inclination.	Horizontal Intensity compared with that of Altona.
Brussels	50°51′ 11″	2° 3′ 46″ W.	67°37′·6	1·034
Cologne	50 56 29	4 37 30 E.	67 11·9	1·049
Bonn	50 43 45	4 45 40 E.	67 2·6	1·058
Gotha	50 57 0	8 23 0 E.	66 48·6	1·051
Gottingen	51 32 0	7 14 0 E.	67 9·1	1·033
Berlin	52 31 0	10 41 46 E.	67 27·4	1·029
Altona	53 32 0	7 36 30 E.	68 27·2	1·000
Amsterdam	52 22 30	2 32 54 E.	68 14·9	1·014
Rotterdam	51 55 19	2 8 59 E.	68 4·6	1·008

Magnetic Observations made in England, in Holland, in Belgium, and in France, by M. Mohmand, Director of the Observatory of Cairo. Reduced to January 1st, 1856.

Stations.	Latitude.	Long. from the merid. of Paris.	Inclination.	Horizontal intensity.	Total absolute value.
Edinburgh	55°57′ 20″	5°31′ 7″ W.	71°20′·5	1·601	5·004
Manchester	53 29 0	4 34 46 W.	69 57·7	1·683	4·912
Liverpool	53 24 40	5 19 19 W.	70 1·0	1·683	4·925
Dublin	53 23 14	8 41 52 W.	70 25·4	1·671	4·975
Cambridge	52 12 50	2 14 31 W.	68 55·3	1·729	4·808
Oxford	51 45 38	3 35 54 W.	68 50·3	1·737	4·812
Kew	51 38 16	2 38 0 W.	68 33·0	1·754	4·798
Greenwich	51 28 39	2 20 24 W.	68 31·2	1·756	4·795
Leyden	52 9 23	2 9 23 E.	68 19·3	1·767	4·784
Amsterdam	52 22 30	2 32 54 E.	68 24·9	1·763	4·792
The Hague	52 4 20	1 58 16 E.	68 18·8	1·768	4·785
Rotterdam	51 55 19	2 8 59 E.	68 12·3	1·773	4·775
Brussels	50 51 11	2 1 46 E.	67 39·8	1·801	4·739
Calais	50 57 33	0 29 0 W.	67 59·5	1·782	4·755
Dieppe	49 55 35	1 15 31 W.	67 22·5	1·825	4·744
Rouen	49 26 29	1 14 32 W.	67 4·0	1·843	4·730
St. Germain	48 34 37	0 14 43 W.	66 31·5	1·882	4·724
Anghien	48 57 56	0 2 9 W.	66 32·0	1·884	4·724
Versailles	48 47 50	0 10 8 W.	66 26·1	1·888	4·722
Paris	48 50 13	- -	66 21·8	1·889	4·722

Observations made in Spain, communicated by MM. Manuel, Rice Senobas.

Stations.	Latitude.	Long. from the merid. of Paris	Declination.	Inclination.	Date.
Madrid . .	40°25′	6° 2′ W.	22°22′ 27″	61°18′·0	1855.
Lisbon . .	38 42	11 29 W.	22 23 . 0	60 50 ·2	1853.
Vigo . .	42 14	11 5 W.	- -	63 21 ·3	„
Ferrol . .	43 29	10 33 W.	- -	63 38 ·0	„
Estaca de Vares	43 47	10 8 W.	- -	64 23 ·9	„
Pasages . .	43 20	4 6 W.	- -	62 55 ·9	„

Rice Senobas has just communicated to us the result of recent observations made at *Lisbon* :—

Declination observed 22nd of July, 1857, by M. Lamont . . . . 21° 44′ 18″
Inclination „ „ „ M. Pegrado . . . . 60 49′ 48″

Utrecht.— From a communication which M. Bangstballot has been good enough to make to us, the declination obtained at Utrecht on August 26, 1857, is 18° 56′ : the inclination, at the same date, is 68° 4′·5.

Austria.— A great number of magnetic stations, placed under the direction of M. Kreil, form in Austria a very complete system. The following Table presents the magnetic elements determined in some of these stations, and the values of which are reduced to Jan. 1., 1850, which is the most recent date for which they have been calculated :—

Stations.	Longitude.	Latitude.	Declination.	Horizontal intensity.	Inclination.	Total intensity.
Padua . .	29°32′	45°24′	15° 9′·8	2·0740	62°50′	4·542
Venice. .	29 59	45 26	15 1 ·1	2·0749	62 43	4·526
Salzbourg .	30 39	47 48	15 16 ·6	1·9612	64 34	4·567
Ancona .	31 9	43 31	14 8 ·4	2·1692	60 57	4·467
Trieste .	31 25	45 39	14 28 ·2	2·0802	62 39	4·528
Laibach .	32 12	46 3	13 58 ·5	2·0690	62 51	4·534
Gratz . .	33 8	47 4	13 49 ·2	2·0363	63 27	4·556
Vienna .	34 2	48 13	13 31 ·1	1·9878	64 20	4·590
Ragusa .	35 47	42 38	12 17 ·8	2·2623	59 27	4·451
Ofen . .	36 48	47 29	12 18 ·6	2·0446	63 13	4·537
Temeswar .	38 52	45 45	10 50 ·0	2·1336	61 39	4·493

The intensities, both horizontal as well as total, are expressed by their absolute values, measured by Gauss's units.

Russia.—The only recent observations, that have been made in Russia, are those of the magnetic observations, the chief of which are St. Petersburg, Catherinburg, Barnaoul, and Nortchinsk.

Stations,	Longitude from merid. of Paris.	Latitude.	Date.	Declination.	Inclination	Horizontal intensity.
St. Petersburg .	27°59′	59°57′	1844	6°26′	70°59′	
			1850	5 50		
			1851	- -	70 49	
			1841	- -	- -	1·652
Catherinburg .	58 14	56 30	1856	7 44		
			1851	- -	70 5·1	
			1841	- -	- -	1·850
Barnaoul . .	- -	- -	1856	8 54		
			1841	- -	68 55	2·061
Nortchinsk .	- -	- -	1856	4 10		
			1851	- -	67 23·	
			1841	- -	- -	2·212
Pekin . . (Russian mission)	114 9	39 54	1851	- -	56 4·3	

We have already given in the text a great number of results obtained by Lieutenant-General Sabine, who directs, as is well known, the magnetic observations in the *British Possessions.*

The following is a Table of the magnetic elements of the four principal stations:—

Stations.	Long. from the merid. of Greenwich.	Latitude.	Declination.	Inclination.	Horizontal intensity.	Date.
Toronto . .	79°21′ W.	45°39′ N	1°33′ W.	75°15′	3·54	1845 to 1847
Hobarton .	147 27 E.	42 45 S.	9 57 E.	−70 34	4·51	1843 to 1848
The Cape .	18 29 E.	33 35 S.	29 7 W.	−53 25	4·46	1841 to 1846
St. Helena .	5 40 W.	15 36 S.	23 51 W.	−22 7	5·57	1844 to 1847

In *India* they have been also actively engaged in determining, in different places, the magnetic elements. The last observations are those which have been made from January to May, 1856, by M. Hermann Schlagintweit, the results of which we give here:

Stations.	Declination.	Inclination.	Date.
Debrooghur (Upper Assam) . . .	2° 8′ E.	38°29′ 17″	Feb. 1856
Fezpore (Brahmapootra River) . .	1 59 E.	37 14 58	Jan. „
Oodulgooria	2 5 E.	26 27 52	Jan. „
Calcutta	2 24 E.	28 6 4	May, „
Benares	1 27 E.	32 40 9	April, „
Lucknow	1 12 E.	35 18 20	April, „
Agra	1 14 E.	- -	April, „

M. Plantamour, Director of the Observatory of *Geneva*, has communicated to us the results of the most recent magnetic observations.

Station.	Declination.	Date.	Inclination.	Date.
Geneva, Lat. 46°11′ 59″	18 56′·76	1843·0	64°40′5	1842·32
Long. 3 19 0 W. of Paris	17 54·39	1853·0	63 59·65	1855·34

A communication from M. Lamont gives to us the results of the last observations made at *Munich*.

Station.	Date.	Mean Declination.	Mean horizontal intensity.
Munich, Lat. 48° 8′ 45″ Long. 9° 16′ 15″ E. of Paris.	1854	15°19′·45	1·9615
	1855	15 11·72	1·9598
	1856	15 5·41	1·9680
	1857	14 57·86	

NOTE D. (P. 342.)

Note upon Electro-Motors.

In speaking of electro-motors, we have given the principal results of M. Jacobi's theory. These results appear remarkable by their generality, and at the same time by their simplicity; but the numerous experiments made for several years upon electro-motor machines, and, in particular, M. Soret's observations, which he has been good enough to communicate to us, show that, in the majority of cases, M. Jacobi's formulæ do not agree with facts. This theory of electro-motors nevertheless remains very useful to be known, for it will always serve as a starting point in this class of researches; and the want of agreement, that is noticed between the results to which it leads and those of observations, only indicates that it is incomplete. We shall therefore give here the summary of it, extracted from a memoir of M. Jacobi's. (*Annales de Chimie et de Physique*, t. xxxiv. p. 451.)

Let there be an electro-motor machine of any form, in which a

current is circulating, but which is maintained at rest. If by κ we designate the electro-motive force of one pair of the battery that is in action, by n the number of pairs, by ρ the total resistance of the circuit, and by $\imath$ the intensity of the current, we shall evidently have the relation

$$\imath = \frac{n\kappa}{\rho}.$$

The apparatus is set in motion; the motion will commence by acceleration, at the same time that the intensity of the current diminishes, — a weakening which the author attributes merely to the induction currents developed by the motion in the helices of the electro-magnets. After a certain time, the needle of a galvanometer introduced into the circuit is seen to stop, and the motion becomes uniform; this is because, at this moment, the intensity i of the current is such that the magnetic actions produce equilibrium with the resistances that are acting upon the machine.

The magnetism, m, of an electro-magnet is proportional to the intensity, i, of the current, and to the number of turns, β, of its helix; so that we have

$$\mathrm{T} = \beta\, i.$$

Now, on account of the state of equilibrium in which all the forces acting upon the movable part of the electro-motor machine are found, the resultant of the resistance R is equal to the mean resultant of the magnetic forces, which has for its factor the square of the constant magnetism developed in the electro-magnets and the soft irons. Thus we have $\mathrm{R} = \beta^2 i^2$, if we do not take account of a factor, independently of the intensity of the current; that is to say, the resultant of the resistances that act upon an electro-motor in motion, is proportional to the square of the intensity of the current that is circulating in it.

Is the velocity, v, with which the apparatus is animated, a function of this same intensity? In fact, designating by i' the intensity of the counter-current, on the other hand, $\imath - i$, the electro-motive force of an induction current developed in the helix of an electro-magnet, under the influence of the motion of another electro-magnet or of a soft iron, is proportional to the magnetism, m, of this latter to the number, β, of the spirals of the helix, and to the relative velocity, that is to say, to the velocity, v, of the apparatus. Besides the quality of the soft iron

cores, their form, their dimensions, and in general the arrangement of the movable parts of the machine in respect to the fixed parts, have an influence over the intensity of the induction current, which M. Jacobi expresses by a co-efficient, x, constant for the same apparatus. From what we have been saying, and recalling to mind that ρ is the total resistance of the circuit in which the induction current also is circulating, we have

$$i' = x \frac{\beta^2 i \nu}{\rho};$$

or, by substituting for i', its value $1-i$,

$$\nu = \rho \frac{(1-i)}{x \beta^2 i}, \text{ or } i = \frac{\rho 1}{\rho + x \beta^2 \nu} = \frac{n K}{\rho + x \beta^2 \nu}.$$

The two elements of the work that is accomplished by the electro-motor, and the expression of which is $R \nu$, are thus found expressed in a function of the intensity i. If the exterior resistance should suffer a change after some instants of an accelerated or retarded motion, during which the intensity of the current varies in the inverse direction, the velocity again becomes constant, at the same time that the intensity of the current and the elements of the new value of the work R_1 and ν_1 are connected with the new value of the intensity i_1 in the same manner as R and ν were with i. We have, therefore, for the general expression of the work, in all the cases of uniform motion which the machine is able to present,

$$T = R \nu = \beta^2 i^2 \times \rho \frac{(1-i)}{x \beta^2 i} = \rho \frac{(1-i) i}{x}.$$

And this is the relation that exists in every electro-motor that is acting in a regular manner between the work; that is to say, the useful effect and the intensity of the current, namely, the expense. It is easy to see that the value of i, which makes T a maximum, is $\frac{1}{2}$, which gives

$$T_0 = \frac{\rho 1^2}{4 x};$$

or, by substituting its value for 1,

$$T_0 = \frac{n^2 k^2}{4 \rho x};$$

and, by repeating this same value of i, in the expressions of R and ν,

$$R_0 = \frac{\beta^2 n^2 k^2}{4\rho^2} \text{ and } \nu_0 = \frac{\rho}{x\beta^2}.$$

We shall not return to what we have said (Vol. III. p. 342.) on the value of T_0, which is independent of β, whilst R_0 and ν_0 depend upon it.

When a battery is in action, we know that the expense is proportional to the intensity of the current and to the number of pairs; so that we have for the expression of the expense, corresponding to the case of maximum work,

$$q_0 = n i_0 = \frac{n^2 k}{2\rho}.$$

We may here make

$$T_0 = q_0 \frac{k}{2x};$$

whence we deduce for the relation $\frac{T_0}{q_0}$, which M. Jacobi designates by E, and to which he gives the name of *economic effect*, the expression

$$E = \frac{k}{2x}.$$

This expression depends only on the electro-motive force, which must be as great as possible; and on the co-efficient x, by which the apparatus is characterised.

If we suppose that the total surface of the battery is alone given, designating by n the unknown number of pairs, by λ the resistance of the unit of surface of the battery, and by λ' the total resistance of the circuit, minus the battery; the total resistance will be

$$\rho = \frac{n^2\lambda}{\sigma} + \lambda', \quad T_0 = \frac{\sigma n^2 k^2}{4x(n^2\lambda + \lambda'\sigma)};$$

an expression which increases with n, and the limit of which is

$$\frac{\sigma k^2}{4x\lambda}.$$

This value is the double of that which is obtained for T_0, in the case of the maximum of magnetization, which takes place, as we know, when the resistance of the battery is equal to the exterior resistance.

The following is M. Soret's communication on the subject of the experiments that he has just made upon certain electro-motor apparatus.

M. Jacobi has directed his attention only to the ordinary case in which the motion of the electro-magnetic machine is accomplished in the natural direction. But his formula may be applied as well to the case in which the machine is compelled to assume a motion in the opposite direction, by the aid of an exterior mechanical force. It is sufficient to give to the velocity v a negative value. In this case, what M. Jacobi has termed the counter-current would become negative; that is to say, in the same direction as the principal current. The total current would then be stronger whilst the machine is animated with a negative velocity than when it is stopped.

When we should give to the machine a negative velocity $= \frac{\rho}{x\beta^2}$, according to the formula $i = \frac{nh}{\rho - x\beta^2 v}$, the total current would acquire an infinite value.

Now, this velocity would not be very considerable, since it is the value which, in a positive direction, would correspond to a maximum of work, which M. Jacobi states that he has arrived at in his experiments. At the same time that the intensity of the current would become infinite, the mechanical work that it would be necessary to employ, in order to give to the machine this negative velocity, would itself become infinite. Finally, by giving to the machine a still greater velocity, the current would change in direction.

Now these results are not realised by experiments. Far from increasing the energy of the current by making the machine move in the reverse direction, its intensity is diminished almost as much as if the motion were direct. We could conceive that the results might not be realized in an absolute manner, while still admitting the general accuracy of the formulæ. From the existence of a maximum of magnetization, certain arrangements adopted in electro-magnetic machines would prevent an unlimited increase in the intensity. But as it is a considerable diminution that is observed, we must seek for the elements neglected in the calculation.

M. Marie Davy has pointed out two of these elements (*Compt. Rendus*, 1855); they are the electric inertia of the conductor

itself and the inertia arising from the induction of the current upon itself by the effect of its circumvolutions. A third and much more important element, which M. Marie Davy will have perhaps pointed out in his last memoir, the title alone of which is mentioned in the *Comptes Rendus*, is that, each time the circuit is closed the bar of soft iron, on becoming magnetized, developes an energetic counter-current, which considerably diminishes the total intensity. At the breaking of the circuit, an increase of intensity takes place, which is manifested by the greater brilliancy of the spark, but which is far from compensating for the preceding diminution. There is, therefore, a *magnetic inertia*, which plays a very important part, as will be made manifest by the three following experiments.

1st.—I took a small Froment's electro-magnetic machine; I removed the wheel that carries the soft iron armatures whose attraction brings about the motion of the machine. The arbor of this wheel, which carries the commutator was left in its place; and it could be set in motion by means of suitable mechanism. On placing a battery in communication with the machine, and leaving this latter at rest, the deviation of the galvanometer introduced into the circuit was 48°; a velocity of 408 turns per minute was given to the machine, the deviation fell to 30°; on further increasing the velocity, the deviation further diminished. Thus, without the machine producing a mechanical work, by the mere fact of magnetic inertia, there is developed a very energetic counter-current.

2nd.—I took a helix, in the axis of which a bar of soft iron could be placed at pleasure; I formed a circuit with a battery and a clock-movement interrupter; a magnetized needle was employed for measuring the intensity of the current. The deviation was notably more feeble when the bar of soft iron was inserted than when it was removed (19° to 20° in the former case; 24° in the latter).

3rd. I took an electro-magnetic machine constructed by Bonijol. In this machine there is only one pair of electro-magnets, which are magnetized and demagnetized so that the current is interrupted in the whole circuit (which does not always take place with Froment's machine, in which the current is always passing in one of the electro-magnets). I placed this apparatus in communication with the battery, by introducing into the circuit a helix whose resistance was comparable with that of the machine. On introducing a bar of soft iron into the axis of the helix, the

motion of the machine is observed to be notably reduced, of which we may be satisfied either by counting the turns or simply by the ear.

These experiments clearly indicate that the magnetization, that is produced by a discontinuous current, diminishes considerably the intensity of the current.

In order to give an idea of the influence that it possesses in the electro-magnetic machine, I will quote the following figures, obtained with Froment's machine :—

Deviation, the machine being at rest - - - - -	57°
„ the machine making 242 revolutions per minute in the natural direction (velocity positive) -	30°
„ the machine making 242 revolutions per minute in the reverse direction (velocity negative)	32°

Thus the current is indeed a little more energetic when the machine is moved in the contrary direction ; but we see how very feeble the difference is.

THE END.

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